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A new perspective on the efficiency of phosphorus fertilizer use

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Abstract

It is commonly believed that the efficiency of phosphorus (P) fertilizer use is low—of the order of 10-25%. When efficiency is assessed using the ‘balance’ method, which takes into account the recovery of P added in previous applications and when an adequate time period is considered, the efficiency of P use is high—up to and sometimes in excess of 80%. It is possible to establish a ‘critical’ level of P for a given soil and farming system and at this level the efficiency of use is at or close to 100%. The objective should be to reach and maintain this critical level to optimize P-use efficiency.

Key Words

Residual phosphorus, critical soil level, strategy

Introduction

The efficient use of phosphorus (P) fertilizer is important for three main reasons (Syers *et al.* 2008): (i) Phosphate rock from which P fertilizer is produced is a finite, non-renewable resource; (ii) P deficiency in soils and crops is still widespread and must be corrected; and (iii) The transfer of soil and fertilizer P to surface waters should be minimized to prevent adverse effects on water quality.

It is commonly believed that the efficiency of P fertilizer use by plants is low, of the order of 10-25% (Lindsay 1979) due to the strong retention (‘fixation’) of phosphate ions by reactive soil components (Sample *et al.* 1980). The small recoveries of added P by plants when calculated using the ‘difference’ method (percent recovery equals P in the crop with added P minus P in the crop without added P divided by the amount of added P times 100), was also taken as evidence that the efficiency of P use was low.

Work by Barrow (1983) questioned the validity of P fixation and proposed that the retention of P by adsorption (surface) reactions and subsequently by absorption following diffusive penetration into soil components (Evans and Syers 1971) was largely reversible over time. This was consistent with evidence from field experiments which indicated that the residues of P added in fertilizers and manures over a number of years could be recovered by crops in subsequent years.

This paper presents the findings of an extensive review, analysis, and synthesis of information on the efficiency of soil and fertilizer P obtained with different crops grown in a range of soils in different agro-ecological zones.

Methodology

Phosphorus use efficiency by a crop must include the recovery of P from a current application and/or the recovery of soil P reserves from past applications. For the latter, long-term experiments, at least 10 years are required. To allow for the recovery of residual P, the balance method for calculating percent recovery (Syers *et al.* 2008) must be used, namely: P uptake by the crop divided by the P applied times 100.

Results

The percent recovery of P from both single and cumulative applications by crops grown on different soils in different climates in Brazil, New Zealand, Western Canada, England, Peru, India, China and the USA indicated that the smallest recovery calculated by the balance method was 43%, many values exceeded 60%, some values exceeded 80% and an occasional value was larger than 100% (for full details see Syers *et al.* (2008)). Percent recovery larger than 100% indicates that P offtake in the harvested crop exceeds the amount of P applied and that soil P reserves are being depleted. To achieve a percent recovery frequently exceeding 60% and indeed up to and exceeding 80%, would not be possible if P was irreversibly fixed in soils, as was previously thought.

Current thinking suggests that much of the inorganic P is retained by soil components with a continuum of bonding energies related largely to the nature of the physical association of P with soil components. This implies that the strength of bonding controls both the availability of P for uptake by plant roots and its extractability by chemical reagents. Thus soil P can be described (using operational definitions) as being readily and less-readily available to plants and as being readily and less-readily extractable by chemical reagents. This is expressed diagrammatically in Figure 1. The key point is the reversible transfer of P between the first three pools and it is in this respect that current understanding of the behavior of soil and fertilizer P differs from earlier thinking; there is much field-based evidence for the reversible transfer of P (Johnston 2001; Syers *et al.* 2008).

Routine soil analysis for plant-available P measures the P in the soil solution and the amount of P in the readily-available pool. Because this is an operationally-defined fraction of soil P, the method of analysis is unimportant. What is essential is that the data obtained accurately characterize a soil in terms of crop response of existing soil P or added P.

The reversible transfer of P between the first three pools in Figure 1 implies equilibrium between the P in these pools. For example, there is a strong, common linear relation between the increase in total and Olsen P in contrasting soils in long-term experiments at Rothamsted, Woburn, and Saxmundham in England; 13% of the increase in total P is extracted by Olsen reagent. Similarly, in an experiment in North Carolina only about 20% of the 1128 kg P/ha added over 9 years was extracted by the Mehlich-1 reagent. Data from these long-term experiments also show that when no P was applied, the decline in Olsen P, in kg/ha, was less than the total P removed by the crops over a number of years, showing that the readily plant-available pool of P was in part replenished by P from the less-readily plant-available pool of P.

The concepts of the behavior of soil and fertilizer P developed here have a number of important practical implications:

1. It is possible to define a 'critical' level of available soil P for a soil and crop at which the yield asymptote is reached. Below the critical level, yield decreases. Increasing available P above the critical level is an unnecessary expense and may contribute to P-induced eutrophication in surface waters;
2. How much P should be added to increase plant-available P to the critical level? Site-specificity of the data requires that much further work is needed. But as an example, when spring barley was grown on a silty clay loam soil at Rothamsted (initially containing 7 mg/kg Olsen P), 264 kg P/ha was added over a six-year period and the P balance (i.e., P remaining in the soil) was 182 kg/ha and this increased Olsen P to 18 mg/kg, i.e., above the critical level of 14 mg Olsen P/kg.

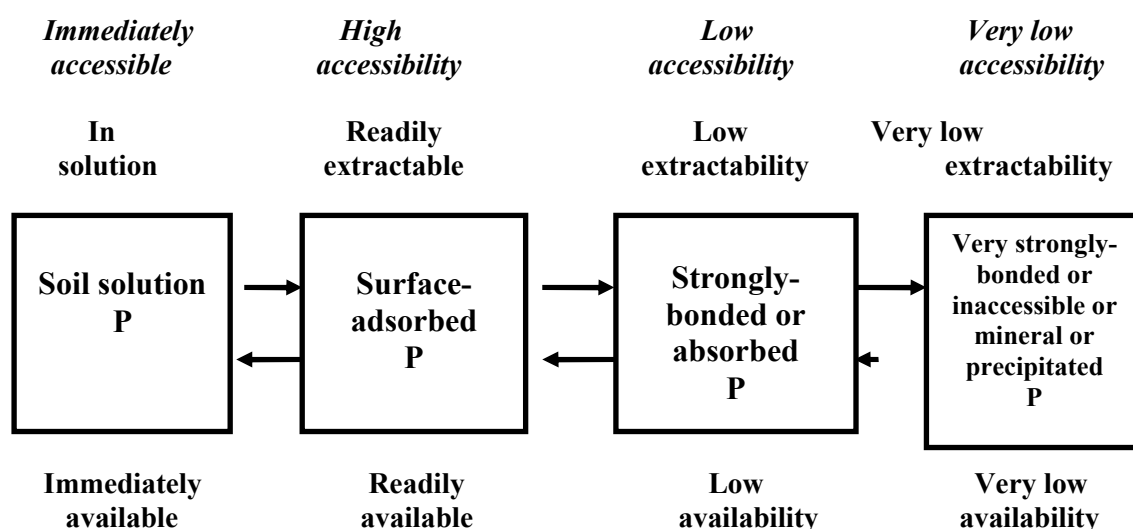


Figure 1. Conceptual diagram for inorganic P forms in soil categorized in terms of accessibility, extractability, and plant availability.

3. How much P is needed to maintain the critical level? Soils at Rothamsted with Olsen P ranging from 9 to 31 mg/kg grew winter wheat between 2002 and 2006 (Table 1). Each autumn 20 kg P/ha was applied to replace the maximum P removed in the harvested grain plus straw and to assess whether this would maintain the Olsen P level. The average maximum annual grain yield was 7.9 t/ha at 23 mg/kg Olsen P; yield was not further increased at 31 mg/kg, but was less than optimum on a soil with 14 mg/kg Olsen P. The maximum offtake of P in grain plus straw was 19 kg/ha and the application of 20 kg/ha maintained the Olsen P at 23 mg/kg. Maintaining the Olsen P at the critical level by replacing the P removed in the harvested crop resulted in 95% efficiency of the applied P when calculated by the balance method.

Table 1. Relationship between Olsen P and winter wheat yields and recovery of added phosphorus, average for 2001-2006, Exhaustion Land experiment, Rothamsted.

Olsen P, mg/kg, in 2004	9	14	23	31
Winter wheat grain, t/ha	7.1	7.8	7.9	7.9
Phosphorus uptake, grain + straw, kg/ha	14	17	19	19
Phosphorus applied annually, kg/ha	20	20	20	20
Percent recovery of applied phosphorus by the balance method	70	85	95	95

Conclusion

The efficient use of P in agriculture is essential to increase and maintain crop yields on many soils, as well as to safeguard the quality of surface waters and conserve resources of phosphate rock. The present study shows that, contrary to common belief, the efficiency of P use is high, up to and in excess of 80% when evaluated by a method which takes into account residual P from previous applications and considered over an adequate period of time. It is possible to identify a critical level of soil P in a particular soil and farming system. Once established, it is only necessary to reach and maintain that critical level to optimize crop yield and the use of other inputs. At the critical level, the efficiency of P use is at or near 100%. What is now required is the development, implementation, and evaluation of strategies for reaching and maintaining the critical level of soil P on a range of soils and in different farming systems so that the high efficiency of P fertilizer use reported here can be achieved more widely.

References

- Barrow J (1983) On the reversibility of phosphate sorption by soils. *Journal of Soil Science* **34**, 751-758.
- Evans TD, Syers JK (1971) Application of autoradiography to study the fate of ³³P labeled orthophosphate to soil crumbs. *Soil Science Society of America Proceedings* **35**, 906-909.
- Johnston AE (2001) Principles of Crop Nutrition for Sustainable Food Production. *Proceedings International Fertilizer Society* **450**, 39p. (York).
- Lindsay WL (1979) Chemical Equilibrium in Soils (Wiley: New York).
- Sample EC, Soper RJ, Racz GJ (1980) Reactions of phosphate fertilizers in soils. In 'The Role of Phosphorus in Agriculture'. (Eds. FE Khasawneh, EJ Sample, EJ Kamprath), pp. 263-310. (American Society of Agronomy: Madison).
- Syers JK, Johnston AE, Curtin D (2008) Efficiency of Soil and Fertilizer Phosphorus: Reconciling Changing Concepts of Soil Phosphorus Behaviour with Agronomic Information. *FAO Fertilizer and Plant Nutrition Bulletin* **18**, 108. (FAO: Rome).

A new site-specific nutrient management approach for maize in the favorable tropical environments of Southeast Asia

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Abstract

The demand for maize in Asia cannot be met despite increases in domestic production and yield in the last 15 years. Further increases in maize yield with good economic returns are feasible in most favorable growing environments of Southeast Asia through relatively straightforward adjustments in crop and nutrient management. More than 120 on-farm experiments with hybrid maize were conducted during 2004-2008 at 19 key production sites in Indonesia, the Philippines, and Vietnam to develop and evaluate a new site-specific nutrient management approach for Asia. Compared to the farmers' practice, SSNM improved yield by about 0.9 to 1.3 Mg/ha across sites in each country. The added net benefit of 184 US\$/ha/crop with SSNM was attributed to increased yield rather than reduced costs of inputs. SSNM increased the agronomic efficiency of N fertilizer by 53% compared to the FFP.

Key Words

Maize, hybrid, site-specific nutrient management.

Introduction

Maize is the second most important cereal crop in Asia, not only as a staple food, but also as a major component of feeds for the animal industry. The total area planted to maize in Southeast Asia is currently about 8.8 million hectares (FAO 2009) with the largest areas in Indonesia (39%), the Philippines (31%), Vietnam (13%), and Thailand (11%). The rapid adoption of high-yielding hybrid maize varieties in Asia has led to significant yield increases in the favorable rainfed and irrigated maize growing areas. However, the growing demand in the region cannot be met despite the increase in domestic production and yield in the last 15 years. For example, Indonesia's maize production and yield continue to increase, and yet the country imported about one million tonnes of maize annually in the last five years (FAO 2009). The average yield of maize in Asia is only 3.9 t/ha (3 to 4 t/ha in Indonesia and Vietnam; 2 t/ha in the Philippines) and knowledge on yield potential, exploitable yield gaps, and constraints to improving productivity at the field level is still limited. In 2004, IPNI launched a multi-national research project in partnership with key institutes in Indonesia, the Philippines, and Vietnam to i) quantify and understand the yield potential of maize in favorable environments and ii) develop and evaluate a new site-specific nutrient management (SSNM) approach and best crop management practices for maize through on-farm research in major maize growing areas. The model Hybrid-Maize (Yang *et al.* 2006) estimates the climatic-genetic yield potential of maize to be in the range of 12 to 14 t/ha, indicating that there is a large scope for further increasing maize production in favorable environments by closing this yield gap.

Materials and Methods

The principles of SSNM for maize were developed through a series of researcher managed on-farm and on-station experiments covering a wide range of bio-physical and socio-economic conditions. On-farm trials with farmer-selected hybrid varieties were conducted for at least two seasons at project sites to estimate yield responses to the application of fertilizer N, P, and K and associated agronomic efficiencies (AE, kg grain increase per kg fertilizer nutrient applied). In the first year, a total of 120 on-farm experiments were set up in farmers' fields at 19 key maize growing sites in Indonesia, the Philippines, and Vietnam. Treatments included nutrient omission plots with ample supply of all nutrients except for the omitted (0-N, 0-P, and 0-K) to estimate nutrient-limited yield, a fully-fertilized NPK treatment with ample application of fertilizer N, P and K to estimate attainable yield, and a farmer's fertilizer practice (FFP) to obtain the actual yield in farmers' fields for comparison. Improved crop management (ICM) treatments were established at all sites but varied from site to site, depending on expected constraints to improving yield in farmers' fields. These treatments included increased planting densities or the application of manure or lime.

SSNM strategies were developed based on the obtained experimental data, updated as more data became available, and used to develop site-specific fertilizer recommendations that were evaluated in subsequent cropping seasons in comparison to the FFP. Data gathered on grain yield, fertilizer NPK use, AEN, fertilizer

cost, revenue, and gross returns from all sites and seasons were pooled and pair-wise treatment differences (Δ) between FFP and SSNM were subjected to analysis of variance (ANOVA) using the SAS Proc Mixed model.

The site-specific nutrient management approach

Site-specific nutrient management is a set of nutrient management principles combined with good crop management practices that will help farmers attain high yield and achieve high profitability both in the short- and medium-term. The SSNM concept was first developed for irrigated rice in Asia (Dobermann *et al.* 2002; Witt *et al.* 2007; IRRI 2007), but the principles are generic and applicable to other crops. SSNM provides an approach for the timely application of fertilizers at optimal rates to fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources, including soil, crop residues, manures, and irrigation water.

Nitrogen (N)

The SSNM strategy for N includes the determination of the total fertilizer N requirement of a maize crop for a given yield target and the distribution of N applications into 2–3 splits to coincide with plant demand at critical growth stages. The total fertilizer N requirement is estimated from the expected grain yield response to fertilizer N and an expected AEN, with the assumption that a greater AEN can be achieved at higher yield responses. Under rainfed environments, adjustments in the timing of N application are needed to ensure sufficient moisture at the time of N application. The leaf color chart can be used to evaluate the plant N demand during the season and the need to adjust the total N rates.

Phosphorus (P) and Potassium (K)

The SSNM approach advocates the sufficient use of fertilizer P and K to overcome deficiencies while simultaneously accounting to some extent for the nutrient removal with harvested products, to avoid the mining of soil P and K. Thus, in addition to the fertilizer required to increase yield, SSNM considers a conservative P maintenance component (accounting for 75% of the P removal with grain) as well as a K maintenance component (accounting for 100% of the K removal with grain).

Results and Discussion

A comparison of the agronomic and economic performance between the SSNM treatment and the FFP is shown in Table 1.

Significantly greater yield (+16%) was achieved with SSNM across all crops and countries. Compared to the farmers' practice, average grain yields in SSNM increased by 0.89 Mg/ha in Indonesia, 1.16 Mg/ha in the Philippines, and 1.25 Mg/ha in Vietnam. Average straw yield increased significantly by 1.37 Mg/ha with SSNM (data not shown), representing a potential benefit in areas where farmers use straw as fuel, forage, or for soil improvement.

SSNM and FFP treatments differed in the amount of N, P, and K applied among the three countries. In the Philippines, N rates were 27.1 kg/ha higher in the SSNM compared to the FFP, but on average across the three countries, 16.1 kg/ha less N was applied in SSNM plots than in FFP. Fertilizer P and K rates with SSNM were slightly higher than in the FFP (+5 kg P/ha and +15 kg K/ha). SSNM led to large gains in N-use efficiency. Average AEN under SSNM rose to 25.1 kg/kg, an increase of 53% compared to the FFP. Better timing and splitting of fertilizer N applications during the season was probably the major reason to the increase in N-use efficiency.

Gross revenue was consistently higher for SSNM than FFP across the three countries. Despite larger investments in seeds (+11%, data not shown) and fertilizer (+6%), the SSNM strategy on average provided added net benefits of 140 US\$ /ha/crop in Indonesia, 103 US\$ /ha/crop in the Philippines, and 218 US\$ /ha/crop in Vietnam.

Table 1. Effect of site-specific nutrient management on grain yield, AEN, fertilizer NPK use, revenue, cost for fertilizer, gross return over seed and fertilizer cost* (2005-2008).

	Levels	Treatment ^B		$\square^C$	P> T ^C	Effects ^D	P> F ^D
		SSNM	FFP				
Grain yield (GY) (Mg/ha)	All ^a	8.32	7.17	1.15	0.000	Country	0.167
	Indonesia	8.79	7.90	0.89	0.000	Site(Country)	0.009
	Philippines	8.52	7.36	1.16	0.007		
	Vietnam	8.09	6.85	1.25	0.000		
Agronomic efficiency of N (AEN) (kg grain kg/N)	All	25.1	16.4	8.7	0.000	Country	0.939
	Indonesia	29.7	21.2	8.5	0.000	Site(Country)	0.273
	Philippines	16.4	11.8	4.6	0.005		
	Vietnam	25.2	15.5	9.7	0.000		
N Fertilizer (FN) (kg/ha)	All	151	167	-16.1	0.000	Country	0.889
	Indonesia	157	192	-35.8	0.000	Site(Country)	0.166
	Philippines	156	129	27.1	0.017		
	Vietnam	148	166	-17.4	0.000		
P Fertilizer (FP) (kg/ha)	All	36	31	5.0	0.007	Country	0.014
	Indonesia	34	24	9.4	0.013	Site(Country)	0.058
	Philippines	32	12	19.8	0.000		
	Vietnam	38	38	0.1	0.961		
K Fertilizer (FK) (kg/ha)	All	79	64	15.3	0.000	Country	0.146
	Indonesia	77	51	25.6	0.019	Site(Country)	0.001
	Philippines	64	20	44.6	0.000		
	Vietnam	83	78	5.1	0.227		
Revenue (GR) (US\$/ha)	All	1,480	1,275	204.4	0.000	Country	0.167
	Indonesia	1,564	1,405	158.7	0.000	Site(Country)	0.009
	Philippines	1,515	1,308	206.6	0.007		
	Vietnam	1,440	1,218	221.7	0.000		
Fertilizer cost (FC) (US\$/ha)	All	258.4	244.8	13.6	0.061	Country	0.000
	Indonesia	255.1	236.4	18.7	0.272	Site(Country)	0.001
	Philippines	238.9	135.7	103.2	0.000		
	Vietnam	263.8	271.0	-7.2	0.361		
Gross returns over seed & fertilizer costs (US\$/ha)	All	1,155	971	184.0	0.000	Country	0.048
	Indonesia	1,246	1,106	140.3	0.000	Site(Country)	0.225
	Philippines	1,199	1,096	102.6	0.099		
	Vietnam	1,110	892	218.1	0.000		

^AAll - all crops grown in Indonesia, Vietnam, and the Philippines from 2005 to 2008; Indonesia: $n = 5$ farms x 5 sites x 1-2 seasons; Philippines: $n = 4$ -11 farms x 3 sites x 1 season; Vietnam: $n = 5$ -13 farms x 11 sites x 1-2 seasons

^BFFP - farmers' fertilizer practice; SSNM – site-specific nutrient management (average of SSNM±ICM);

^C $\square$ = SSNM - FFP. $P>|T|$ - probability of a significant mean difference between SSNM and FFP.

^DSource of variation of analysis of variance of the difference between SSNM and FFP by farm; Prob>|F| = probability of a significant F-value.

* Average regional prices for 2004-2007.

Conclusions and outlook

Yield and profitability of maize in the favorable tropical environments of Southeast Asia can be further increased with improved crop and nutrient management practices. The SSNM concept demonstrated significant agronomic and economic potential in these environments and merits wide-scale dissemination. A number of delivery tools will be released in 2010 to facilitate the introduction of general best management practice for maize in large scale extension campaigns in Indonesia, the Philippines, and Vietnam. These include site-specific Quick Guides on SSNM generated by the *Nutrient Expert for Hybrid Maize* - a new, computer-based decision support software, country-specific training videos on relevant aspects of crop and nutrient management, and a Practical Guide to nutrient management.

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References

- Dobermann A, Witt C, Dawe D, Abdulrachman S, Gines HC, Nagarajan R, Satawatananont S, Son TT, Tan CS, Wang GH, Chien NV, Thoa VTK, Phung CV, Stalin P, Muthukrishnan P, Ravi V, Babu M, Chatuporn S, Sookthongsa J, Sun Q, Fu R, Simbahan GC, Adviento MAA. 2002. Site-specific nutrient management for intensive rice cropping systems in Asia. *Field Crops Res.* 74:37-66.
- FAO. 2009. FAOSTAT [online]. In: www.fao.org. Available at <http://faostat.fao.org> (last update 2009; accessed 18 May 2009). Rome, Italy: Food and Agriculture Organization (FAO).
- IRRI. 2007. Site-specific nutrient management [online]. Available at www.irri.org/irrc/ssnm (last update 2007; accessed 05 Dec. 2007).
- Witt C, Buresh RJ, Peng S, Balasubramanian V, Dobermann A. 2007. Nutrient Management. In: Fairhurst TH, Witt C, Buresh RJ, Dobermann A, editors. *Rice: a practical guide to nutrient management*. 2nd edition. International Rice Research Institute (IRRI), Philippines, International Plant Nutrition Institute (IPNI) and International Potash Institute (IPI), Singapore. p 1-45.
- Yang HS, Dobermann A, Cassman KG, Walters DT. 2006. Hybrid-Maize (ver. 2006). A simulation model for corn growth and yield. Nebraska Cooperative Extension CD 9 [online]. Available at <http://www.hybridmaize.unl.edu/Index.htm> (last update 2006; accessed 29 Nov. 2006). Lincoln, NE: University of Nebraska.

Acidification of volcanic ash soils under oil palm in Papua New Guinea: effects of fertiliser type and placement

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Abstract

Soil acidification is a widespread degradation problem, but little information is available for oil palm production systems. The aim of this work was to determine the effect of fertiliser type and placement on acidification of volcanic ash soils under oil palm in Papua New Guinea. A field trial, which had various combinations of N (114-120 kg N/(ha.year)) and K (329 kg K/(ha.year)) fertilisers applied over 13 years, was examined. Over that period, pH_{water} of the 0-0.2m layer declined by 0.38 units in the control treatment and 0.52-0.96 units in the fertilised treatments. Application of fertiliser and plant residues are not uniform in oil palm plantations, so the effect of placement was measured in another trial, which had been operating for 6 years. In the 0-0.05 m layer, the decrease in pH_{water} due to fertiliser addition (ammonium chloride plus kieserite) was least (0.52 units) when fertiliser was applied in the weeded circle and greatest (1.03 units) when it was applied in the frond pile. Soil pH buffer capacity was different between zones and fertiliser treatments, but the difference in acidification effect of fertiliser between zones was attributed primarily to differences in the water balance and N cycling rather than pH buffer capacity.

Key Words

Exchangeable cations, net acid addition rate, pH buffer capacity, nitrogen fertiliser, potassium fertiliser.

Introduction

Oil palm (*Elaeis guineensis* Jacq.) is grown on over 100 million ha in the humid tropics and the area is expanding in response to demand for vegetable oil. Being a perennial tree crop it is a good candidate for sustainable agricultural systems, but soil acidification is a potential soil degradation issue, especially since ammonium fertilisers came into use in the 1980s. There is a reasonable amount of information on soil acidification in a number of tropical agricultural systems (Moody and Aitken 1997), but there is little published information on soil acidification under oil palm, probably largely because of the tolerance of oil palm to acidic conditions. Research in Malaysia and Africa indicates substantial acidification due to fertiliser applications (Kee *et al.* 1996; Roth *et al.* 1986). In Papua New Guinea (PNG), most oil palm is grown on fertile recent volcanic ash soils. Nitrogen fertiliser (mostly ammonium-based) is used in most plantations due to large economic responses. High rainfall rates and permeable soils mean that nitrate losses by leaching can be considerable (Banabas *et al.* 2008a; 2008b), so soil acidification is likely. In addition, considerable removal of cations in produce could be expected to accelerate acidification. Most of these cations are returned to the field in by-products from the oil mill, but only to fields close to the mill, for economic and logistical reasons. In this work we set out to determine the rate of soil pH decline and acidification under oil palm grown on recent volcanic ash soils of PNG, using two fertiliser trials run by the PNG Oil Palm Research Association. The aims of the work were to determine a) the effect of fertiliser type on acidification, and b) the effect of fertiliser placement on acidification and pH buffering capacity.

Methods

Field trial descriptions

The effect of fertiliser type was measured in Ambogo plantation, Oro Province (Trial 309). The site has an annual average rainfall of 2,214 mm, and silty to sandy loam soil derived from alluvially deposited volcanic ash. The trial was a latin square design with 5 treatments, 5 replicates and 36-palm plots, of which the central 16 were monitored. Treatments were application (annual rates) of: no fertiliser; ammonium chloride (AC) alone at 3.2 kg/palm; ammonium sulphate (SOA) alone at 4.0 kg/palm; and SOA (4.0 kg/palm) together with potassium chloride (MOP) at 4.4 kg/palm or bunch ash (BA) at 8.8 kg/palm. The BA, which supplied the same amount of K as the MOP, was produced by burning the empty fruit bunches (EFB) that are a by-product of palm oil production. The trial was conducted in a field that had been planted in 1980 at 143 palms/ha, and treatments ran from 1990 until 2001. In 1989, before treatments were imposed, soil samples

were taken from each plot (0-0.2 m depth). Each sample was a composite of samples taken from 5 pits within each plot. The pits were located in the corners and the middle of the plot, exactly between two palms (equivalent to the BP zone in Figure 1). This zone receives some fertiliser, with most of the remainder falling on the frond pile (Figure 1). In 2002 soil samples were taken again, in the same way as the first sampling.

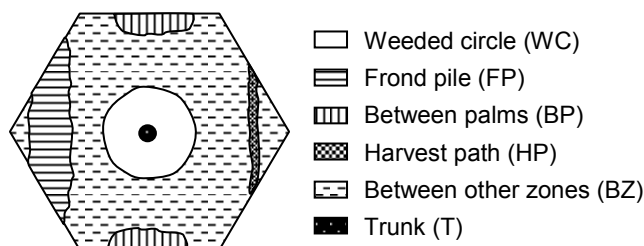


Figure 1. Surface management zones in the fertiliser trials. The hexagon, whose perimeter is defined by the midpoint between adjacent palms, represents the repeating unit in oil palm plantations. Empty fruit bunches (EFB) were applied to the BP zone in some treatments in Trial 129 but none in Trial 309.

The effects of fertiliser placement and EFB application were measured in Kumbango plantation, West New Britain Province (Trial 129). The site has an annual average rainfall of 3,248 mm and clayey recent volcanic ash soils, with some inter-bedded pumice. The trial was a randomised complete block design, with 4 replicates, 36-palm plots, of which the central 16 were monitored, and treatments involving placement of fertiliser in different locations; either on the 'weeded circle' (WC), the 'frond pile' (FP), or the 'between palms' (BP) zones (Figure 1). The BP zone had no EFB applied in some treatments and EFB applied in other treatments (50 t/(ha.year)). The fertiliser was AC (3 kg/palm) plus kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$, 3 kg/palm) annually. The trial was conducted in a field that had been planted in 1994 at 135 palms/ha, and treatments were imposed from 1998 until 2004. In 2004, soil was sampled from all application zones at depth increments of 0-0.05 and 0.05-0.1 m. Each sample from each plot, zone and depth increment was a composite of 8 samples, which were taken from two points adjacent to 4 different palms.

Soil analyses and calculation of net acid addition rate and pH buffer capacity

In both trials, all soils were analysed for pH (pH_{water} , 1:2 soil:water for Trial 309 and 1:5 for Trial 129), exchangeable cations, cation exchange capacity (CEC) and organic C content, and selected samples were analysed for bulk density and pH buffer capacity by titration (pHBC, calculated by linear regression of titration curves). In Trial 309, net acid addition rate (NAAR) was calculated by multiplying the pH change by pH buffer capacity (24.6 mmol/(kg.pH unit)) and bulk density (1.14 Mg/m^3).

Results

In Trial 309, soil pH declined and exchangeable acidity increased in all treatments, with pH of the 0-0.2 m layer dropping by 0.38 units in the nil treatment and 0.52-0.96 units in the fertilized treatments (Figure 2). Addition of SOA or AC accelerated pH decline by 0.023 units/year compared to the control treatment. Addition of SOA together with MOP accelerated pH decline by 0.042 units/year compared to the control, whereas BA had an ameliorative affect on pH compared to SOA alone (Figure 2). There were substantial decreases in exchangeable Ca and Mg and CEC with time in all fertilised treatments except SOA+BA (Figure 1). NAARs for the top 0.2m were 1.6, 3.1, 2.5, 4.2 and 2.3 kmol/(ha.year) for the nil, AC, SOA, SOA+MOP and SOA+BA treatments, respectively. In the fertilised plots the NAARs were less than the potential NAAR calculated from nitrification and uptake or leaching loss of nitrate (8-17 kmol/(ha.year)), possibly because the 0-0.2 m depth layer of the BP zone was not representative of the whole field.

In Trial 129, pH and the effects of fertilisers on pH differed markedly between management zones (Table 1). Without fertiliser addition, pH was lowest in the WC, which had lowest organic matter content of all the zones, and highest in the FP and BP+EFB zones, which had the highest organic matter contents. In all zones pH was lowest in the surface layer. The decrease in pH of the 0-0.05 m layer due to fertiliser addition was least (0.52 units) when fertiliser was applied in the WC and greatest (1.17 units) when fertiliser was applied in the FP. The difference in pH decline between zones may have been due to differences in N transformations and fluxes, or to differences in pHBC. Soil pHBC did indeed differ between zones (Figure 3), in relation to their organic matter contents (Figure 4). The greatest decline in pH occurred in the FP and BP zones, despite them having high organic matter contents and pHBC. Therefore, the difference in

acidification rates between zones appears to have been primarily due to differences in N cycling processes. The pH decline due to fertiliser addition in Trial 129 was accompanied by large decreases in exchangeable cation contents, especially Ca (Table 1). Addition of EFB (without fertiliser) resulted in an increase in pH, CEC and exchangeable Mg and K, but a decrease in exchangeable Ca (Table 1).

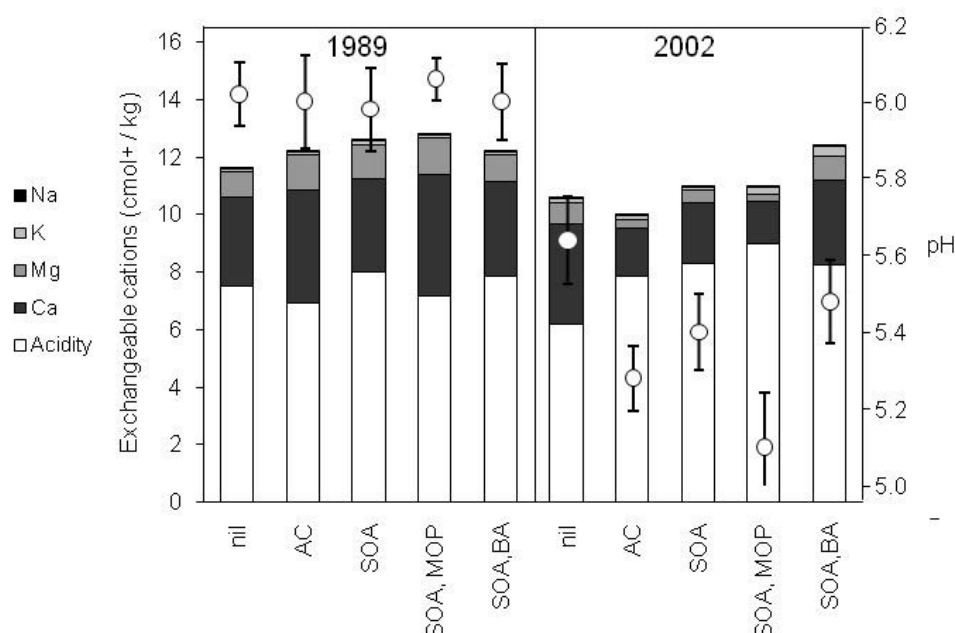


Figure 2. Mean exchangeable cation content (bars) and mean pH_{water} (circles ±s.d.) of soil in the BP zone of Trial 309 (0-0.2 m depth). Order of cations in the bar graph is the same as in the legend.

Table 1. Effect of fertiliser application and placement on soil properties in Trial 129. Values are the mean of 4 replicates.

	0-0.05 m depth				0.05-0.10 m depth			
	WC zone	FP zone	BP (+EFB)	BP (-EFB)	WC zone	FP zone	BP (+EFB)	BP (-EFB)
pH _{water} (- fert.)	5.52	5.98	6.01	5.82	5.74	6.01	6.45	5.92
pH _{water} (+ fert.)	5.00	4.81	5.26		5.08	4.98	5.46	
Org. C (-fert.), %	3.9	10.4	11.4	4.0	2.7	4.9	5.1	3.1
Org. C (+fert.), %	3.3	9.3	14.4		2.6	5.1	6.1	
CEC (- fert.), cmol+/kg	6.5	28.4	26.5	10.1	5.7	16.5	18.5	7.6
CEC (+ fert.), cmol+/kg	2.9	10.1	22.8		2.1	6.0	13.6	
Ex. Ca (- fert.), cmol+/kg	24.8	27.8	28.2	36.1	20.2	26.3	25.2	33.5
Ex. Ca (+ fert.), cmol+/kg	2.2	8.0	19.0		1.8	4.4	9.9	
Ex. Mg (- fert.), cmol+/kg	0.71	4.07	4.52	1.40	0.55	2.33	4.18	1.10
Ex. Mg (+ fert.), cmol+/kg	0.44	3.50	9.84		0.38	1.69	5.99	
Ex. K (- fert.), cmol+/kg	0.42	1.28	0.72	0.56	0.42	1.31	1.50	0.56
Ex. K (+ fert.), cmol+/kg	0.29	0.80	0.85		0.24	0.53	0.70	

Discussion

It is difficult to accurately assess acidification of soil under oil palm, due to the large spatial variability in throughfall, water uptake, fertiliser application, and organic matter content (due to placement of pruned fronds in FP, prevention of understory growth in the WC, and application of EFB to the BP zone in some plantations). The NAARs that we measured over a 13-year time period were quite low compared to the values calculated for various tropical agricultural systems by Moody and Aitken (1997). That difference could be due to several factors. Firstly, NAAR was calculated for the 0-0.2 m layer only. Deeper in the profile there were also differences in soil pH between treatments (results not reported here), but the deeper analyses were carried out in 2002 only, so could not be used to calculate NAAR. Secondly, it is possible that NAAR is lower under oil palm than other crops, due to the large net primary productivity and high rates of recycling of organic matter. Thirdly, it is possible that the measurements made in the BP zone did not properly account for NAAR over the whole field, due to localised acidification in certain places. Certainly, acidification rates, as determined in the 6-year old trial, were highly variable spatially.

The relatively low acidification rate in the WC is likely to result from low losses of nitrate by leaching in that zone. Nitrate loss is a function of deep drainage loss, which is likely to be low in the WC due to low throughfall and high uptake in this zone. In contrast, the FP and BP zones have higher throughfall and lower uptake (Banabas *et al.* 2008a; Nelson *et al.* 2006). In addition, differences in acidification rates between zones would have been influenced by differences in the area over which fertiliser was spread.

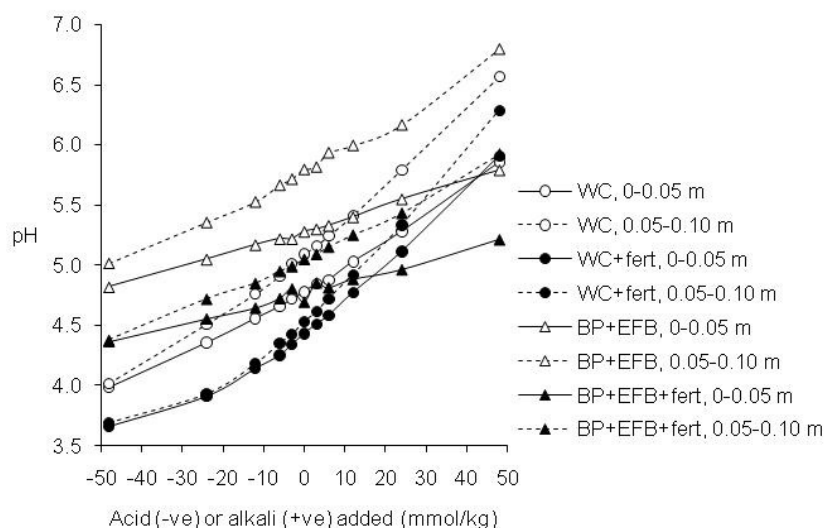


Figure 3. pH buffering titration curves of soil from selected zones in Trial 129.

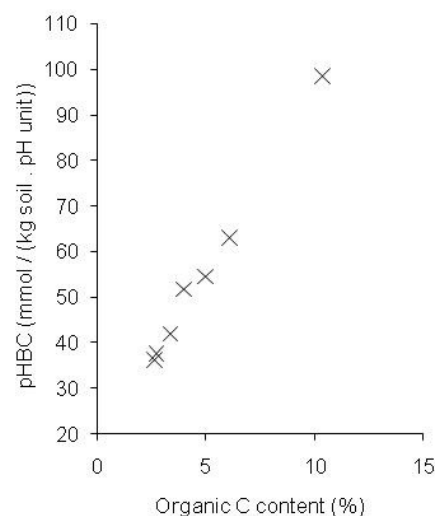


Figure 4. pHBC as a function of organic C content (Trial 129).

Conclusions

Under oil palm, there was significant acidification of volcanic ash soil with time, with or without fertiliser application, despite the soil's relatively high CEC and organic matter content. Addition of ammonium-based fertilisers significantly accelerated pH decline, with combined addition of MOP enhancing the decline. The effect of fertiliser addition on acidification was spatially variable, being greatest when fertiliser was applied in the FP and BP zones, probably due to a high proportion of the N being lost by leaching in those zones.

Acknowledgments

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References

- Banabas M, Turner MA, Scotter DR, Nelson PN (2008a) Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 1. Water balance, and nitrogen in soil solution and runoff. *Australian Journal of Soil Research* **46**, 332-339.
- Banabas M, Scotter DR, Turner MA (2008b) Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 2. Nitrogen transformations and leaching, and a residence time model. *Australian Journal of Soil Research* **46**, 340-347.
- Kee KK, Goh KJ, Chew PS (1995) Effects of NK fertiliser on soil pH and exchangeable K status on acid soils in an oil palm plantation in Malaysia. In 'Plant Soil Interactions at Low pH'. (Eds RA Dale, NJ Grundon, GE Rayment, ME Probert) pp. 809-815. (Kluwer: Amsterdam)
- Moody PW, Aitken RL (1997) Soil acidification under some tropical agricultural systems. 1. Rates of acidification and contributing factors. *Australian Journal of Soil Research* **35**, 163-173.
- Nelson PN, Banabas M, Scotter DR, Webb MJ (2006) Using soil water depletion to measure spatial distribution of root activity in oil palm (*Elaeis guineensis* Jacq.) plantations. *Plant and Soil* **286**, 109-121.
- Roth CH, Wildhagen H, Meyer B (1986) Comparison of nutrient balances of small-holder and industrial oil-palm plantations on ferrallitic soils of the Sedimentary Basin of southern Ivory Coast. *Plant and Soil* **91**, 257-267.

Ammonia volatilisation from urea fertiliser products applied to an alkaline soil

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Abstract

A static chamber system was used to measure the levels of ammonia volatilisation from 7 urea-based fertiliser products and one non-urea based nitrogen fertiliser, applied to the surface of a Calcixerollic xerochrept. Ammonium sulfate, urea, urea coated with sulfur (2 levels), urea coated with polymer (2 levels) and zinc-coated urea (2 levels) were applied to the surface of the alkaline soil and incubated in sealed jars for 4 and 7 days. Ammonia volatilisation levels varied from 4.9% for ammonium sulfate to 7.9% for one of the zinc-coated urea products, after 7 days of incubation. There was no significant difference between urea and any of the urea-coated fertilisers. Significantly higher levels of ammonia were volatilised after 7 days compared to 4 days. The levels of volatilisation were low compared with other studies, possibly caused by low levels of urease activity in the soil used. In addition, the lack of inhibition of volatilisation by the surface-coated fertilisers was in contrast to previous findings.

Key Words

Ammonia volatilisation, urea; sulfur, polymer.

Introduction

Reviews of gaseous nitrogen emissions from fertiliser products (Harrison and Webb 2001; Sommer *et al.* 2004) have indicated the serious consequences of agriculture on global emissions. These include acidification of soils and eutrophication of waters from rainfall deposition (Draaijers *et al.* 1989, Harrison and Webb 2001; Sommer *et al.* 2004). The other result of atmospheric losses is the effect on farmers in terms of reduced nitrogen use efficiency in soil nutrient transport. This may encourage higher rates of usage of nitrogen fertiliser to compensate for losses associated with its application. Alternatively, there may be a more recent trend to reduce levels of fertiliser use and encourage more efficient utilisation (Sommer *et al.* 2004). Globally, urea has been the most used form of nitrogen fertiliser accounting for 46% of all usage (Watson 2000) because it is the cheapest form of solid N fertiliser to produce and has the highest N content. However it is also one of the more inefficient forms of N fertiliser owing to losses, which have been reported to occur by NH₃ volatilisation. The levels of NH₃ release reported vary considerably, and factors such as temperature, soil pH, soil and atmospheric moisture, wind velocity and soil organic carbon levels all add to the complexity of the process. Previous studies have involved a range of techniques performed in both laboratory and field situations (Fenn and Hossner 1985; Gameh *et al.* 1990; Gioacchini *et al.* 2002; Sigunda *et al.* 2002; Sommer *et al.* 2004; Zaman *et al.* 2008). In attempts to reduce losses through NH₃ volatilisation various coatings and treatment have been applied to urea and other N fertilisers include polymers (Blaise and Prasad 1995; Rochette *et al.* 2009a), elemental S (Prasad 1976; Knight *et al.* 2007), urease and nitrification inhibitors (Gioacchini *et al.* 2002; Asing *et al.* 2008, Zaman *et al.* 2008). This study aimed to quantify the effect of different urea granule surface treatments on the extent of ammonia volatilisation on a calcareous soil.

Methods

Soil

A Calcixerollic xerochrept from Cungena, South Australia was used in this study. A sample from the 0-10 cm depth layer of this soil was air dried and sieved to <2.0 mm prior to use. This soil had the following chemical properties: Total C 4.9 mg C/g soil; organic C 0.6 mg C/g soil; CaCO₃ 35.7 %; pH (1:5 soil:water) 8.4.

Fertilisers

Eight fertilisers were used in this study: ammonium sulphate (AS), urea (U), sulfur-coated urea 5% (US 5%), sulfur-coated urea 10% (US 10%), polymer-coated urea 2L/t (UP 2L), polymer-coated urea 4L/t (UP 4L), zinc sulphate-coated urea 0.8% Zn (ACT 117) and Zn:PEI-coated urea 1.0% Zn (ACT 118).

Incubation experiment

Experiments were conducted using glass jars of approximately 800 mL capacity (Ball® Quart Wide Mouth Jar, Alltrista Consumer Products Company) fitted with gas-tight lids. The lids were fitted with a stainless steel septum port containing a gas tight rubber septum through which a needle could be inserted. The Cungena soil (17 g) was packed to a bulk density of 1.4 g cm^{-3} in individual PVC cores (37 mm ID x 50 mm high) fitted with nylon mesh ($0.75 \text{ }\mu\text{m}$, Australian Filter Specialists) at their base. The packed soils were adjusted to 70% water filled pore space (WFPS). Individual soil cores were placed into the incubation jars together with a polycarbonate vial containing 10 mL of reverse osmosis water to help maintain headspace humidity and reduce any drying of the soil. The soil samples were pre-incubated for 7 days at 25°C prior to imposing fertiliser treatments. Weighed fertiliser granules were placed on the surface of the soil cores. A 40 mL polycarbonate vial containing 20 mL of 0.5 M KHSO_4 was placed in each jar with the soil samples to trap any ammonia that would volatilise and the jars were resealed. The fertiliser products used contained different concentrations of nitrogen and the mass of fertiliser added to each core was adjusted to give an addition of approximately 12 mg N / core (equivalent to 100 kg N / ha).

A full factorial design with four replicates of each combination of 10 fertiliser treatments and two incubation times (4 and 7 days) was used, and an incubation temperature of 25°C was maintained throughout. The fertiliser treatments included the application of individual granules from each of the eight fertilisers as well as a no soil control treatment and a soil with no fertiliser treatment. An additional 12 jars were prepared in which duplicate 0, 1, 2, 3, 4 or 5 mL volumes of 0.5 M $(\text{NH}_4)_2\text{SO}_4$ were injected into 10 mL of 1 M NaOH in the same trapping system. A further 6 jars in which duplicate 0, 2 or 4 mL volumes were directly injected into 20 mL of 0.5M KHSO_4 solution were also included. These series of jars were used as controls to ensure that the incubation system was quantitatively trapping ammonia. The KHSO_4 ammonia trapping solutions were removed from half the jars after 4 days of incubation and from the remaining jars after 7 days. Aliquots of the KHSO_4 solution (2 mL) were removed from the ammonia traps and added to 8 mL of reverse osmosis water. The ammonium concentration of the diluted samples was determined using an automated segmented flow analyser (Alpkem Flow Solution 3) and used to calculate the proportion of applied fertiliser N that volatilised.

Statistical analysis

A two-way ANOVA was used to determine the effects of the ten fertiliser treatments x two incubation times on ammonium recovery in the trap solution. Significant differences ($P \leq 0.05$) between means were identified using a Tukey's HSD multiple comparison technique. All analyses were completed using GenStat 12th Edition (Payne *et al.* 2009) or Statistica Version 8 (StatSoft 2007).

Results

Recovery of ammonia where solutions of ammonium sulphate were injected directly into the KHSO_4 traps and injected into an alkaline solution were quantitative ranging from 100.9 to 106.1%. This result confirmed the ability of the experimental apparatus to capture any ammonia volatilised from the soils amended with N fertilisers.

For the Cungena soil, the main effects of fertiliser type and incubation time were significant but the interaction between fertiliser type and incubation time was not (Table 2). No ammonia was volatilised from the unamended Cungena soil. Volatilisation from ammonium sulfate on Cungena soil was 4.9% which was significantly less ($P < 0.05$) than from all the other fertilisers (Figure 1a). Losses from urea compounds ranged from 6.5 to 7.9% of applied N. There was no significant difference in volatilisation between urea and urea plus sulfur (US 5%), urea plus polymer (UP 2L and UP 4L) and urea product ACT 118. However, volatilisation was significantly higher for urea plus sulfur (US 10%) and for product ACT 117. Mean volatilisation after 4 days incubation was 5.7% of applied N, which was significantly lower than 7.9% after 7 days incubation ($P < 0.001$) (Figure 1b).

Table 2. *P*-values derived from the ANOVA completed for the proportion of added fertiliser N that volatilised from the Cungena soil.

ANOVA Effect	Cungena soil
Fertiliser type	<0.001
Incubation duration	<0.001
Fertiliser type x duration	0.192

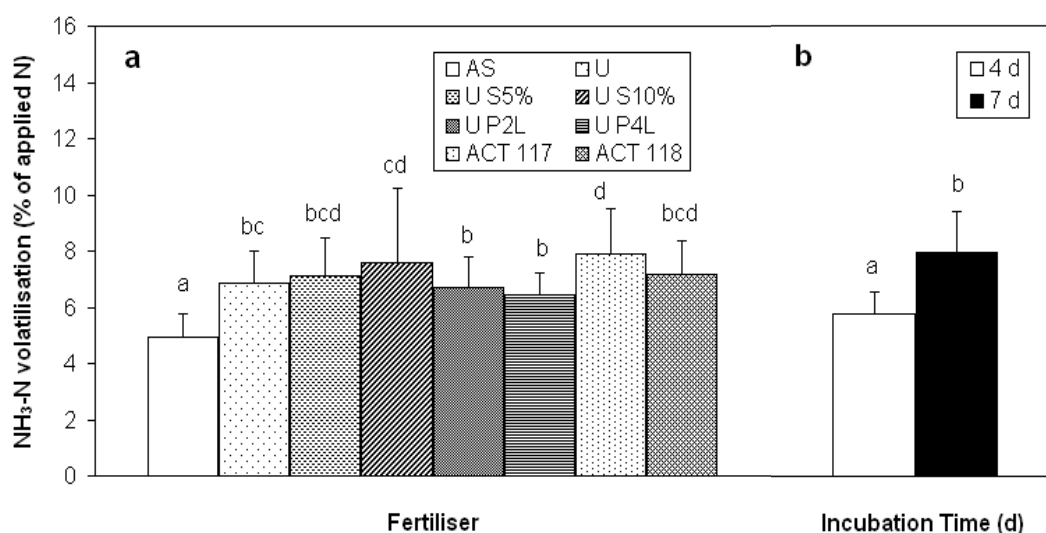


Figure 1. Ammonia volatilisation from 8 fertiliser products applied to Cungena soil and incubated for 4 or 7 days. Explanation of symbols is found in Methods section. NH₃-N recovery is expressed as the % of applied N that was volatilised. (a) the main effect of fertiliser type and (b) the main effect of incubation duration. Bars indicate ± 1 standard deviation of the mean ($n=4$). Letters denote significant differences between means of each fertiliser type within each incubation period ($P=0.05$).

The levels of volatilisation from all fertiliser treatments shown in this experiment are at the lower end of results reported elsewhere (Fenn and Hossner 1985; Harrison and Webb 2001; Sommer *et al.* 2004). Maximum losses from Cungena soil were 7.9% of applied N. Gameh *et al.* (1990), in a laboratory chamber study, reported losses of up to 28% of added N from one soil, while around fourfold less N was lost from a second soil. It was suggested that the lower levels of volatilisation in that study were caused by lower air exchange rates compared with other studies, but that the relative treatment effects should still remain valid. Almost all volatilisation had occurred after 7 days for fertilisers applied to Cungena soil. Similar N losses of 9% were reported from a field study by Rochette *et al.* (2009a) for urea surface broadcast over a dry acidic soil with an incubation time of 25 days. Using a similar soil, but this time as intact cores in a laboratory chamber experiment, Rochette *et al.* (2009b) reported N losses of 21% from no tilled treatments but only 4% from traditionally ploughed treatments. Urease activity was observed to be higher in the no till soils, while the presence of residues on the surface of the no till soil prevented contact of the urea granules with the soil and that may have reduced adsorption of NH_4^+ on soil particles. The low organic carbon levels in the Cungena soil may also have resulted in low urease activity and consequently low volatilisation in this soil.

There was no evidence of inhibition of volatilisation by any of the products containing sulfur, polymer or zinc coatings. This contrasts with previous findings of a volatilisation reduction of up to 40% over urea levels, from polymer-coated urea (Blaise and Prasad 1995). Rochette *et al.* (2009a) showed a reduction from 9% volatilisation with urea to 4% from a polymer-coated product, and Knight *et al.* (2007) reported a polymer compound which showed zero volatilisation. Reductions in urea volatilisation levels ranging from 23% to 61% have reported for sulfur coated urea (Prasad 1976; Knight *et al.* 2007).

Conclusions

The levels of volatilisation from this experiment were low compared with those from published studies, ranging from 4.9% to 7.9%. All urea products showed significantly higher volatilisation than ammonium sulfate. Urea products coated with sulfur (10%) and with zinc (0.8%) showed significantly higher levels of volatilisation compared to uncoated urea. There were no coated products that indicated reduced volatilisation compared to uncoated urea. Volatilisation levels increased after 4 days to near maximum levels after 7 days. Low urease activity, which may occur in this soil because of its low organic carbon levels, could have contributed to the low levels of ammonia volatilisation reported here.

References

Asing J, Saggarr S, Singh J, Nolan NS (2008) Assessment of nitrogen losses from urea and an organic manure with and without nitrification inhibitor, dicyandiamide, applied to lettuce under glasshouse conditions. *Australian Journal of Soil Research* **46**, 535-541.

- Blaise D, Prasad R (1995) Effect of blending urea with pyrite or coating urea with polymer on ammonia volatilization loss from surface-applied prilled urea. *Biology and Fertility of Soils* **20**, 83-85.
- Draaijers GPJ, Ivens WPMF, Bos MM, Bleuten W (1989) The contribution of ammonia emissions from agriculture to the deposition of acidifying and eutrophying compounds onto forests. *Environmental Pollution* **60**, 55-66.
- Fenn LB, Hossner IR (1985) Ammonia volatilisation from ammonium or ammonium forming nitrogen fertilizers. *Advances in Soil Science* **1**, 771-776.
- Gameh MA, Angle JS, Axley JH (1990) Effects of urea-potassium chloride and nitrogen transformations on ammonia volatilization from urea. *Soil Science Society of America Journal* **54**, 1768-1772.
- Gioacchini P, Nastri A, Marzodori C, Giovannini C, Antisari LV, Gassa C (2002) Influence of urease and nitrification inhibitors on N losses from soil fertilized with urea. *Biology and Fertility of Soils* **36**, 125-131.
- Harrison R, Webb J (2001) A review of the effect of N fertilizer type on gaseous emissions. *Advances in Agronomy* **71**, 65-108.
- Knight EC, Guertal, EA, Wood CW (2007) Mowing and nitrogen source effects on ammonia volatilisation from turfgrass. *Crop Science* **47**, 1628-34.
- Payne RW, Murray DA, Harding SA, Baird DB, Soutar DM (2009) 'GenStat for Windows (12th Edition) Introduction'. (VSN International: Hemel Hempstead).
- Prasad, M (1976) Gaseous loss of ammonia from sulfur-coated urea, ammonium sulfate, and urea applied to a calcareous soil (pH 7.3). *Soil Science Society of America Journal* **40**, 130-134.
- Rochette P, MacDonald JD, Angers DA, Chantigny MH, Gasser M, Bertrand N (2009a) Banding of urea increased ammonia volatilisation in a dry acidic soil. *Journal of Environmental Quality* **38**, 1383-1390.
- Rochette P, Angers DA, Chantigny MH, MacDonald JD, Bissonnette N, Bertrand N (2009b) Ammonia volatilization following surface application of urea to tilled and non-tilled soils: A laboratory comparison. *Soil and Tillage Research* **103**, 310-315.
- Sigunga DO, Janssen BH, Oenema O (2002) Ammonia volatilization from vertisols. *European Journal of Soil Science* **53**, 195-202.
- Sommer SG, Schjoerring JK, Denmead OT (2004) Ammonia emission from mineral fertilizers and fertilized crops. *Advances in Agronomy* **82**, 557-622.
- StatSoft Inc, 2003. Statistica (data analysis software system), Version 8.0 (StatSoft Pacific Pty Ltd.: Melbourne, Australia).
- Watson CJ (2000) Urease activity and inhibition – principles and practice. In 'Proceedings of the International Fertilizer Society'.
- Zaman M, Nguyen MI, Blennerhassett JD, Quin BF (2008) Reducing NH₃, N₂O and NO₃⁻-N losses from a pasture soil with urease or nitrification inhibitors and elemental S-amended nitrogenous fertilizers. *Biology and Fertility of Soils* **44**, 693-705.

Ammonia volatilization: On-farm assessment of the amount and timing of nitrogen fertilizer application in corn production

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Abstract

An on-farm field experiment was carried out for three years at Ottawa, ON and two years at Guelph, ON and Saint-Valentin, QC, Canada. Our objectives were to (1) quantify the flux and the amount of NH₃ volatilization as affected by the rate and time of N fertilizer; (2) assess the impact of rainfall and soil temperatures on NH₃ volatilization; and (3) determine the threshold level of N fertilizer at which large NH₃ volatilization losses occur. Using the static chamber method, NH₃ volatilization was monitored after preplant or sidedress N application. Rate of NH₃ volatilization peaked at 3 to 7 d and then dropped sharply within the next 7 d before levelling off in the following weeks. The amount of NH₃ volatilization increased with increasing N levels applied preplant or sidedress at all site-yrs. Peak NH₃ volatilization ranged from 40 to 8000 g N/ha/d after preplant fertilization and from about 100 to 2100 g N/ha/d after sidedress, resulting in NH₃ losses of 0.1 to 47 kg N/ha and 0.6 to 20 kg N/ha, respectively. Our data clearly indicate that sidedress applications may reduce NH₃ volatilization losses simply due to lower total N rates.

Key Words

Corn or maize, peak emissions, environmental factors, N fertilization, minimizing NH₃ volatilization

Introduction

The global synthetic N input increased sharply in the past 50 yr and NH₃ volatilization still is one of the main loss pathways for the applied N. In Canada, an estimated 584×10^3 Mg N was released into the atmosphere as NH₃ in 2002 (Environment Canada 2004), and agriculture activities accounted for 91% of the total NH₃ emission (Chambers *et al.* 2001). Grain corn (*Zea mays* L.) is the main field crop covering a large portion of cropland in eastern Canada. Corn requires larger quantities of N nutrition during the growing season than other small grain cereal crops (Ma and Dwyer 1998). Ammonia volatilization from corn fields depends on fertilizer type, rate, and timing of application (Keller and Mengel 1986; Rozas *et al.* 1999), soil characteristics (Oberle and Bundy 1987), soil temperatures (Rozas *et al.* 1999), rainfall events (Zhu *et al.* 2000), and agronomic measures such as use of urease inhibitors (Rozas *et al.* 1999).

The objectives of this on-farm research were to (1) qualify the magnitude of NH₃ volatilization from the corn agroecosystem after chemical fertilizer N input at several sites from central and eastern Ontario to southern Quebec; (2) identify environmental factors or on-farm practices that minimize NH₃ volatilization; and (3) determine the practical level of fertilizer N application that resulted in the minimum NH₃ volatilization loss.

Materials and Methods

An on-farm field experiment assessing the amount and timing of N fertilizer application to corn on NH₃ volatilization was carried out in Ottawa, ON (45° 18' N, 75° 43' W) from 2005 to 2007, and in Guelph, ON (43° 34' N, 80° 25' W) and Saint-Valentin, QC (45° 05' N, 73° 21' W) in 2006 and 2007.

The experiment, which consisted of 14 to 18 combinations of rate and timing of N fertilizer application, was arranged in a randomized complete block design with four replications in each site-yr (Ma *et al.* 2010a). A subset of the treatments with the same rate and application timing of N were chosen for monitoring NH₃ volatilization (Ma *et al.* 2010b). Preplant N fertilizer (urea) at the designated rates was broadcast and incorporated with a cultivator on the same day as planting. For sidedress application, urea ammonium nitrate (UAN; 275 g N/kg) was applied as a single band furrow (10 cm wide by 10 cm deep) between adjacent corn rows, at the V6 to V8 growth stage.

A semi-open static cylinder system (Oberle and Bundy 1987) was used to monitor NH₃ volatilization from the plots. The measuring discs were collected at 1, 3, 7, 14, 21 and 28 d after fertilizer application. Sidedress

plots received 30 kg N/ha at preplant, and thus there were two periods of 28-d NH₃ monitoring in these plots. Precipitation, air and soil temperatures were recorded hourly at the experimental sites using automated weather stations. All the data were subjected to analysis of variances using the GLM procedure of SAS.

Results and Discussion

Ammonia volatilization induced by preplant nitrogen application

With zero N applications, NH₃ volatilization was on average 39 g N/ha/d, but ranged from 0 to 116 g N/ha/d, which was primarily affected by soil disturbance associated with field operations and complicated by rainfall events. Increasing N supply increased the rate of NH₃ volatilization sharply ($P < 0.05$), with peak readings of 40 to 8000 g N/ha/d which occurred primarily within 3 to 7 d after fertilizer application (Figure 1).

Ammonia volatilization induced by nitrogen fertilizer applied at sidedress

The rate of NH₃ volatilization increased with sidedress N fertilizer applied as a single band at the V6 to V8 growth stage. In all cases, there was a negligible rate of NH₃ volatilization in the zero N plots; while NH₃ volatilization increased with increasing fertilizer N rates in five out of seven site-yr, except for Guelph in 2006 and 2007 (Figure 2).

Grain yields in this study ranged from 6.3 to 10.8 Mg/ha, and responded to the applied N fertilizer quadratically with a similar trend for preplant and sidedress application. In nearly all cases, except for the Ottawa site in 2005, the calculated maximum economic optimum rates of N were from 90 to 130 kg N/ha. In comparison, producers usually apply 150 kg N/ha for grain corn production in this region. Both total cumulative and specific NH₃ volatilizations increased exponentially with the applied N fertilizer rates (Figure 3). Specific NH₃ volatilization, i.e. total NH₃ emission (kg NH₃-N/ha) as a function of corn grain yield (Mg/ha) being produced, increased from about 0.10 to 0.94 kg NH₃-N Mg⁻¹ grain for preplant, or to 0.77 kg NH₃-N Mg⁻¹ for sidedress application (Figure 3), in this cool and humid region (Ma *et al.* 2010b).

Conclusions

In eastern Canada, NH₃ volatilization induced by N fertilizer in corn fields through soil-atmosphere interface ranged from 0.1 to 47 kg N/ha after preplant N application and from 0.6 to 20 kg N ha⁻¹ after sidedress at the V6-V8 growth stage, respectively. This fertilizer-induced NH₃ emission accounted for 0.1 to 38% of preplant and 0.3 to 13% of sidedress N application in these two periods. In general, the peak emission occurred within the first and the second week after fertilizer N was incorporated before planting or sidedress in a single band at the V6 to V8 growth stage, respectively. Fertilizer induced NH₃ emission was sustained for 4 wk or shorter. Total cumulative NH₃ losses increased with increasing N fertilizer rates. The most important factor controlling NH₃ loss was rainfall, and its effect was complicated by other factors including soil texture, fertilizer timing and soil disturbance. No rainfall within one month after pre-planting fertilization resulted in low NH₃ volatilization, as observed at the Guelph site in 2006. Such conditions occurred infrequently in this region. A lack of rainfall within 10 to 14 d after fertilization usually induced negligible amount of total NH₃ volatilization, but soil moisture conditions before and after a rainfall event appeared to be a controlling factor. However, the impediment effect from the rain was ephemeral and other factors could take over the control shortly. Although it is difficult to make a general conclusion about the timing and levels of N fertilization to corn, it appeared that potential losses are equally variable from both timings and that loss at each timing is related to rainfall/soil moisture conditions at the time of application. Clear evidence indicates that sidedress applications enable reduction in total N fertilizer input for economic crop yields, and may reduce NH₃ losses simply due to lower fertilizer rates.

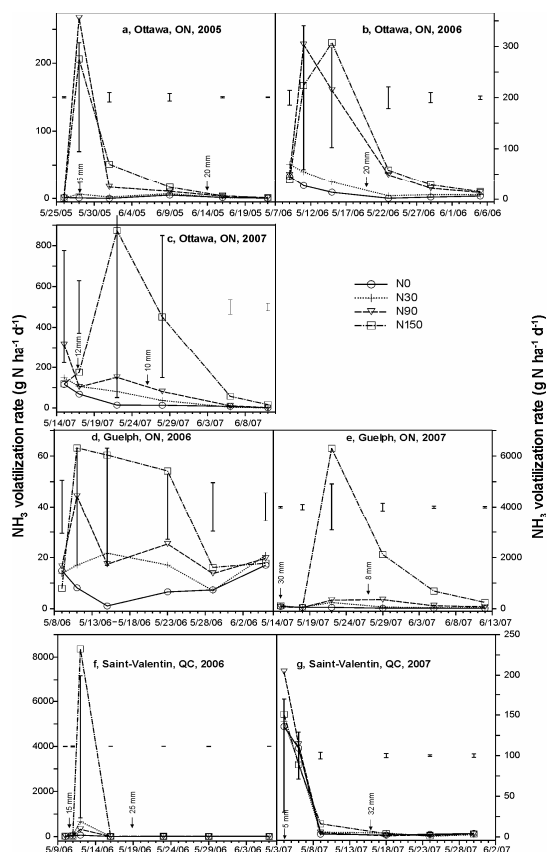


Figure 1. Rate of ammonia volatilization within 4 wk after N was incorporated right before planting at the sites. The vertical bars represent $LSD_{0.05}$ values.

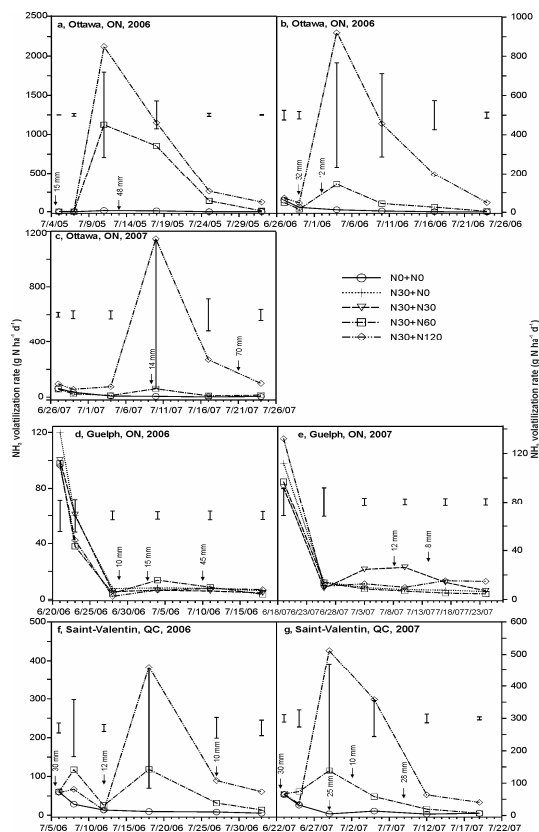


Figure 2. Rate of ammonia volatilization within 4 wk after N was banded at V6-V8 growth stages at all site-years. The vertical bars represent $LSD_{0.05}$ values.

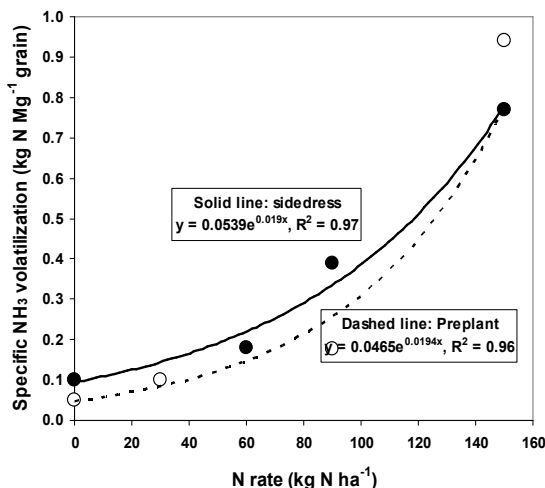
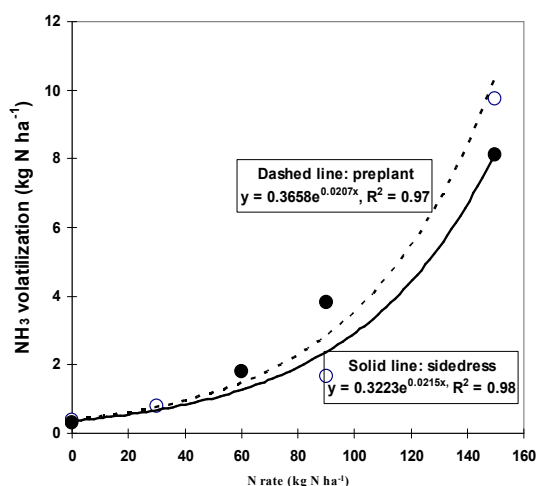


Figure 3. Total and specific NH_3 emissions (i.e. total NH_3 volatilization as a function of corn grain yield being produced) as affected by preplant and sidedress N application to corn, averaged across seven site-years in Ontario and Quebec.

References

- Chambers PA, Guy M, Roberts ES, Charlton MN, Kent R, Gagnon C, Grove G, Foster N (2001) Nutrients and their impact on the Canadian environment. Agriculture and Agri-Food Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada and Natural Resources Canada, Ottawa. 241p.
- Environment Canada, Meteorological Service of Canada (2004) 2004 Canadian acid deposition science assessment. Cat. No. En4-46/2004E-MRC.

- Keller G D and D B Mengel (1986) Ammonia volatilization from nitrogen fertilizers surface applied to no-till corn. *Soil Science Society of America Journal* **50**, 1060-1063.
- Ma BL, Dwyer LM (1998) Nitrogen uptake and utilization of two contrasting maize hybrids differing in leaf senescence. *Plant and Soil* **199**, 283-291.
- Ma BL, Wu TY, Tremblay N, Deen W, McLaughlin NB, Morrison MJ, Gregorich EG, Stewart G (2010a) Nitrous oxide fluxes from corn fields: on-farm assessment of the amount and timing of nitrogen fertilizer. *Global Chang Biology* **16**, 156-170.
- Ma BL, Wu TY, Tremblay N, Deen W, McLaughlin NB, Morrison MJ, Stewart G (2010b) Rate and timing effects of fertilizer nitrogen application to corn on ammonia volatilization in cool and humid regions. *Agronomy Journal* **102**, 134-144.
- Oberle SL, Bundy LG (1987) Ammonia volatilization from nitrogen fertilizers surface-applied to corn (*Zea mays*) and grass pasture (*Dactylis glomerata*). *Biology and Fertility of Soils* **4**, 185-192.
- Rozas HS, Echeverría HE, Studdert GA, Andrade FH (1999) No-till maize nitrogen uptake and yield: effect of urease inhibitor and application time. *Agronomy Journal* **91**, 950-955.
- Zhu T, Pattey E, Desjardins RL (2000) Relaxed eddy-accumulation technique for measuring ammonia volatilization. *Environmental Science and Technology* **34**, 199-203.

Comparing the risk of phosphorus runoff following single and split phosphorus fertiliser applications in two contrasting catchments using rainfall simulation and Bayesian modeling

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Abstract

In this study we applied a Bayesian modeling approach to investigate the comparative risk of P runoff following single and split P fertilizer applications in two catchments with contrasting rainfall/runoff patterns. Split P fertiliser strategies are commonly used in intensive pasture production in Australia and our results showed that 3 applications of 13.3 kg P/ha resulted in a greater risk of P runoff compared to a single application of 40 kg P/ha, when rainfall simulation experimental data and long term surface runoff data were combined in a Bayesian P risk model. Splitting P fertiliser applications increased the likelihood of a coincidence of fertiliser application and runoff occurring. We found that the overall risk of P runoff is also increased in catchments where the rainfall/runoff pattern is less predictable, compared to catchments where rainfall/runoff is winter dominant. We suggest that land managers apply P fertiliser less frequently and only during periods of the year when surface P runoff risk is low.

Introduction

The general increase in soil phosphorus (P) fertility concentrations to optimum or above optimum levels under intensively managed pastures in Australia has contributed to greater adoption of a strategy of split P maintenance applications, (i.e. multiple small applications within a year), which in total are equivalent to the annual maintenance P requirements. Although lower rates of P generally resulted in lower surface runoff P concentration in Australian (Greenhill *et al.* 1983; Austin *et al.* 1996; Dougherty *et al.* 2008), Chinese (Zhang *et al.* 2003) and USA studies (Sharpley 1982), there has been very limited research comparing P losses generated from several smaller applications of P to the same total P rate applied in a single application. This information is essential as lower runoff concentrations associated with multiple smaller applications may be countered by the greater likelihood of runoff occurring soon after one of these applications.

It is important that interactions between P fertiliser rate and timing of runoff are placed in a context which will allow farmers and advisors to make more informed nutrient management decisions. One method of achieving this is to use a Bayesian modelling approach to investigate the key periods in a year when the risk of surface P runoff from a particular P fertiliser strategy is highest. Bayesian risk models can be created using long term surface runoff data from catchments which broadly represent the rainfall/runoff pattern typical for the industry/region in question. Therefore, the objectives of the current study were to a) compare runoff P concentrations under simulated rainfall following 0 kg P/ha, a single application of 40 kg P/ha and 3 applications of 13.3 kg P/ha, and b) use this knowledge to assess the risk of the two different P fertiliser strategies on surface P runoff in two catchments with contrasting rainfall/runoff patterns using a Bayesian risk model.

Methods

Re-packed boxes and surface runoff

A sandy loam, classified as a Oxyaquic Hydrosol (Isbell 1996), with a high P fertility (Olsen P = 49 mg/kg) and low P buffering index (Burkitt *et al.* 2008) of 115 and low oxalate extractable Al concentration of 1193 mg/kg was sampled to a depth of 100 mm. The topsoil (0-20 mm) was collected separately from the subsoil (20-100 mm) and re-packed into 108 plywood boxes (800 mm long, 200 mm wide, 100 mm deep), using a modified method from SERA-17 (2004). Re-packed soil was sown with perennial ryegrass and 3 P fertiliser treatments [as triple superphosphate (21% P, 1% S)] were surface applied to soil once ryegrass had established and soil had equilibrated for a period of 4 months. Treatments included a control (0 kg P/ha), a single application of 40 kg P/ha (applied on day 0) and 40 kg P/ha applied as 3 split applications of 13.3 kg P/ha (applied on days 0, 25 and 50). Treatments were applied immediately after pasture was harvested at day 0, 25 and 50 and the experiment included 3 pasture regrowth cycles (total of 74 days). Surface runoff was generated by applying artificial rainfall (<0.01 mg P/L) to each box on 15 separate days (Figure 1), with

boxes inclined at a slope of 5%, and receiving rainfall for 20 minutes after surface runoff began at an intensity of 50 mm/h $\pm$ 2 mm. Surface runoff sub-samples were filtered (<0.45 μ m) and analysed for dissolved reactive P (DRP) using the molybdenum blue method. Unfiltered samples were analysed for total P (TP) and were analysed using an alkaline persulfate digestion followed by colorimetry.

Long term catchment surface runoff data and Bayesian P runoff model

Long term modeled surface runoff data (1961-2008) from two contrasting catchments (Montagu catchment in far north west Tasmania and Ansons Bay catchment in north east Tasmania) were used to represent 2 contrasting rainfall/runoff patterns, which commonly support intensively managed pastures in Australia. Surface runoff for both catchments were estimated over the period 1960-2008 using modeled outputs from the Australian Water Balance Model (AWBM) (Boughton 2004). Rainfall and evaporation were estimated using catchment averages of an interpolated climate grid from the Australian Bureau of Meteorology SILO. The models were calibrated using river flow records from the Water Information Systems Tasmania and the Rainfall Runoff Library using the Rosenbrock Single start method (Rosenbrock 1960). Bayesian analysis was firstly used to determine the area under the curve (mg P/days/L) from the data in Figure 1, then used to obtain a measure of the annual P runoff risk throughout the year by firstly calculating the probability for every day of the year that the surface flow exceeded the 90th quantile and using this as the probability of P in surface runoff, if the initial runoff occurred on each day of the year (day 1-365) in turn, up to 74 days after initial P application. The maximum P concentration would be the area under the curve from T0 to T74, but this was reduced proportionally based on the probability of surface flow. A posterior distribution is the probability distribution for a parameter given the observed data and prior knowledge, and represents the probabilities of the values that a parameter may take; a posterior mean is simply the mean of the posterior distribution. We compared posterior statistics using a Bayesian test of significance and results were highly significant when $P > 0.95$ and suggestive of a significant difference when $P > 0.90$. We fitted the model using Markov Chain Monte-Carlo simulation by means of JAGS software (Plummer 2009). The model was run for 40,000 iterations and a 50% burn-in was used.

Results and discussion

Data from this study reveal that increases in P concentration with increasing P fertiliser rate are not linear and that higher rates of P fertiliser result in disproportionately higher P concentrations (Figure 1). The first application of 13.3 kg P/ha resulted in TP concentrations (mean of 9.5 mg P/L), which were approximately one fifth of that measured immediately following the application of 40 kg P/ha (mean of 44 mg P/L). These findings are consistent with those reported by Dougherty *et al.* (2008), but contrast with Austin *et al.* (1996) and Greenhill *et al.* (1983) who found a linear relationship between rate of P fertiliser applied and runoff P concentration. The apparent contrast between studies may reflect differences in soil properties as the low P sorbing soil used in the current study may have had insufficient P sorption sites to rapidly sorb the highest rate of P fertiliser applied.

Although the mean area under the curve suggested that a single application of 40 kg P/ha resulted in more P runoff (data not presented), when these data were incorporated into a Bayesian runoff P risk model that considered runoff probability, this finding did not hold. In the case of the Montagu catchment with the more strongly winter dominant runoff pattern, 3 applications of 13.3 kg P/ha significantly increased the risk of surface P runoff in comparison to a single application of 40 kg P/ha (Figure 2). Although the significance was only suggestive ($P > 0.90$), 3 applications of 13.3 kg P/ha were also more risky in terms of P runoff in the Ansons Bay catchment. These findings confirm that although the lower P rates used in the split P treatment resulted in less TP runoff (area under the curve), the greater number of P applications (3 vs 1) increased the risk of exposure of these P applications to surface runoff over an annual rainfall/runoff cycle. This suggests that in a nutrient management scenario, single, annual applications of P fertiliser are likely to result in lower risk of P runoff losses, especially if P fertiliser application can be applied when the chances of surface runoff are less likely (i.e. summer). When the risk of P runoff in the two catchments were compared, it was clear that the more erratic rainfall/runoff pattern typical of the Ansons Bay is inherently more risky in terms of P runoff, compared to winter dominant rainfall/runoff pattern of the Montagu catchment. Although it may be possible to slightly reduce the risk of surface P runoff by adhering to weather forecasts prior to P fertiliser application, there is anecdotal evidence that weather forecasts in catchments which have more erratic rainfall/runoff patterns – such as occurs more frequently as you move up the east coast of Australia, are less reliable, further complicating a manager's capacity to reduce P runoff risk.

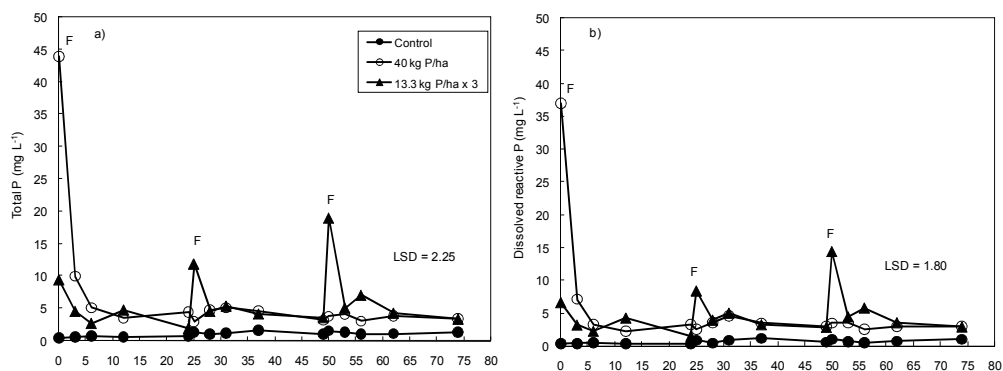


Figure 1. Relationships between a) TP and b) DRP concentration (mean of replicates) in surface runoff and cumulative day for the control, 40 kg P/ha and 3 x 13.3 kg P/ha treatments. LSD represents the least significant difference for cumulative days. Fertiliser applications are indicated by F.

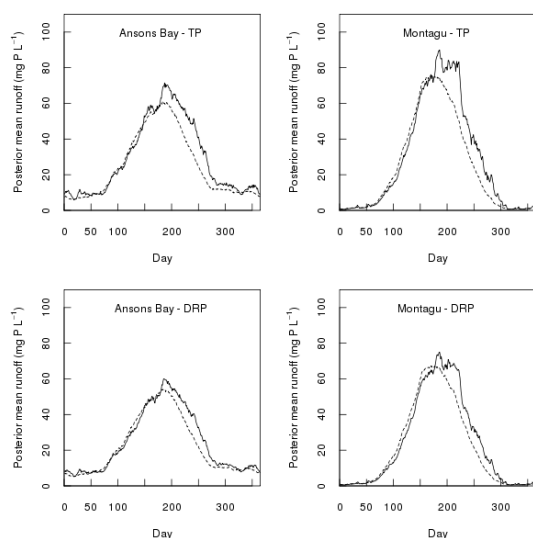


Figure 2. Bayesian posterior mean TP and DRP runoff (mg P/L) for Ansons Bay and Montagu catchments for the single application of 40 kg P/ha (solid line) and 3 applications of 13.3 kg P/ha (dashed line).

Conclusions

Although higher rates of P fertiliser resulted in disproportionately higher runoff P concentrations from individual events, the Bayesian risk modeling used in the current study suggested that splitting P fertiliser applications into 3 applications tended to increase the overall risk of P loss in runoff, in comparison to a single application. We found that the risk of P runoff from these split P fertiliser strategies was even greater in catchments where the rainfall/runoff pattern was less predictable. Land managers should be encouraged to only apply P fertiliser when absolutely necessary to optimise pasture production. If P fertiliser is to be applied, it should be applied either in dry periods of the year, or applied less frequently to minimise runoff risk.

References

- Austin N, Prendergast J, Collins M (1996) Phosphorus losses in irrigation runoff from fertilized pasture. *Journal of Environmental Quality* 25, 63-68.
- Boughton W (2004) The Australian water balance model. *Environmental Modelling and Software* 19, 943-956.
- Burkitt L, Sale P, Gourley C (2008) Soil phosphorus buffering measures should not be adjusted for current phosphorus fertility. *Australian Journal of Soil Research* 46, 676-685.
- Dougherty WJ, Nicholls PJ, Milham PJ, Havilah EJ, Lawrie RA (2008) Phosphorus fertilizer and grazing management effects on phosphorus in runoff from dairy pastures. *Journal of Environmental Quality* 37, 417-428.
- Greenhill NB, Peverill KI, Douglas LA (1983) Nutrient concentrations in runoff from pasture in Westernport, Victoria. *Australian Journal of Soil Research* 21, 139-145.

- Isbell RF (1996) 'The Australian Soil Classification.' (CSIRO Publishing: Melbourne).
- Plummer M (2009) Just another Gibbs sampler software. 7/9/2009. (SourceForge Open Source Software).
- Rosenbrock HH (1960) An automatic method for finding the greatest or least value of a function. *Computer Journal* 3, 175-184.
- SERA-17 (2004) National research project for simulated rainfall-surface runoff studies.
http://www.sera17.ext.vt.edu/Documents/National_P_protocol.pdf
- Sharpley AN (1982) Prediction of water-extractable phosphorus content of soil following a phosphorus addition. *Journal of Environmental Quality* 11, 166-170.
- Zhang H, Cao Z, Wang G, Zhang H, Wong MH (2003) Winter runoff losses of phosphorus from paddy soils in the Taihu Lake Region of South China. *Chemosphere* 52, 1461-1466.

Computational method for appropriate nitrogen level by soil diagnostics in Andosols of Japan

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Abstract

In farm production, it is important to reduce the cost of production and increase yield. It is necessary that countries like Japan that depend on import for resources reduce the quantity of the chemical fertilizer consumed in the cost of production. In this study, it was aimed to develop the soil diagnosis formula that was able to decide the appropriate amount of chemical fertilizer nitrogen. The evaluation method of available nitrogen of the soil was examined in the beginning. As a result, the phosphate buffer extractable N (PB-N) that used an oven dry (160 °C, 2 hour) soil sample was adopted for available nitrogen. Next, the amount of the chemical fertilizer nitrogen absorbed by Chinese cabbage, corn, and carrot was measured using ¹⁵N labelled ammonium sulphate. The multiple linear regression analysis was calculated using as dependent variable the absorbed chemical fertilizer nitrogen and explanatory variable that was the total amount of nitrogen absorption of crops, inorganic nitrogen, and available nitrogen. This multiple regression equation was adopted as a soil diagnosis formula. As a result, the amount of chemical fertilizer nitrogen was able to be reduced, while maintaining yield.

Key Words

Nitrogen excess, nitrogen cycle, nutrient management tool.

Introduction

A lot of studies report on soil fertility deterioration (Hartemink 1997). On the other hand, there is a region where the production conditions have deteriorated, along with soil eutrophication due to excessive fertilizer, use. Understanding available nitrogen (N) is important for optimizing N fertilizer recommendations (Matsumoto *et. al.* 2000). To estimate N fertility, a 4 week incubation method measuring the amount of inorganic N released during incubation at 30 °C under field moisture conditions has been commonly used. However, there is little research from which an accurate amount of applied nutrient is calculated using available N. One of the problems is the time taken for the 4 week incubation method of analysis. In Japan, because this method and the correlations were high, a simple expedient method, 1/15M phosphate buffer at pH 7.0 extraction, was used (Saito 1988). Higuchi (1981) reported that 1/15M phosphate buffer (pH 7.0) extracted the Protein-like N compounds in soil. In fact, the 4 week incubation method evaluates the inorganic N, and 1/15M phosphate buffer at pH 7.0 extraction method is a method of evaluating the organic N. However, this simple analysis method had not been used for the soil diagnostics in Japan. It is because the accuracy of this simple method is low. The purpose of this study is to examine the analysis method to solve such a problem, and to develop a method of diagnosing the soil to calculate an appropriate amount of the chemical fertilizer N. The reduction in the energy cost and the decrease of the negative environmental impact can be expected by advising the appropriate amount of the chemical fertilizer N, while maintaining or improving agricultural production.

Methods and Materials

The soil samples used in all the analyses are Andosols from Japan. All samples were air dried once and a part of the samples were oven dried for 160 °C, 2 hour in a glass bottle. For the 4 week incubation N (4w-N), 10 g of air and oven dry soil samples in a 100 mL plastic bottle was moistened at 60 % of maximum water-holding capacity. These bottles were covered with polyethylene, and the soils were incubated at 30 °C for 28 days. After incubation, the inorganic N in a soil was extracted with 10 % KCl and determined by FIA (flow-injection analyser). A 10 g air and oven dry soil samples with 40 mL of 1/15 M phosphate buffer (pH 7.0) consisting of Na₂HPO₄·12H₂O (14.6 g/L) and KH₂PO₄ (3.5 g/L) was shaken for 1 hour to extract the organic N (PB-N). The soil extracts were passed through No. 6 filter paper (Advantec), and the organic N was measured by the steam distillation method. The concentration of protein in the soil extract with phosphate buffer was measured by a protein assay kit (Bio-Rad), which applied the Bradford method using g-globulin as a standard. Inorganic N was filtered after it was extracted by using 50 mL of 10 % KCl solution and soil

10g, and measured with FIA. The cultivation experiment followed using Chinese cabbage, corn and carrot. The field where the diagnosis formula was developed and the cultivation examination field were at different locations.

Results and Discussion

Development of the index of available N by simple analysis

As compared with air dry soil samples, oven dry soil samples showed the higher values for phosphate buffer extractable N (PB-N) and 4 week incubation N (4w-N) (Figure 1). By heating (160 °C, 2 hour), the correlation coefficient of PB-N and 4w-N increased (Figure 1). By heating, some of the soil microbes die out. As for the increase in amount of 4w-N, the mineralization of dead bodies of these soil microbes was considered to be the cause. However, this process alone cannot explain the increase in PB-N. It is because N of soil microbe origin is contained in PB-N. It is difficult to think that microbes increase by heating at high temperature and for short time. By heating, the amount of total N in the soil samples did not decrease (Figure 2). On the other hand, Protein N in Phosphate buffer extraction sample tends to increase a little with PB-N by heating (Figure 2). These results show that PB-N of oven dry samples contains easily decomposable organic matter. When carrying out soil diagnosis, it is desirable that the spread and dispersion of measured values become small. Therefore, it was thought that PB-N was suitable as an index of available N.

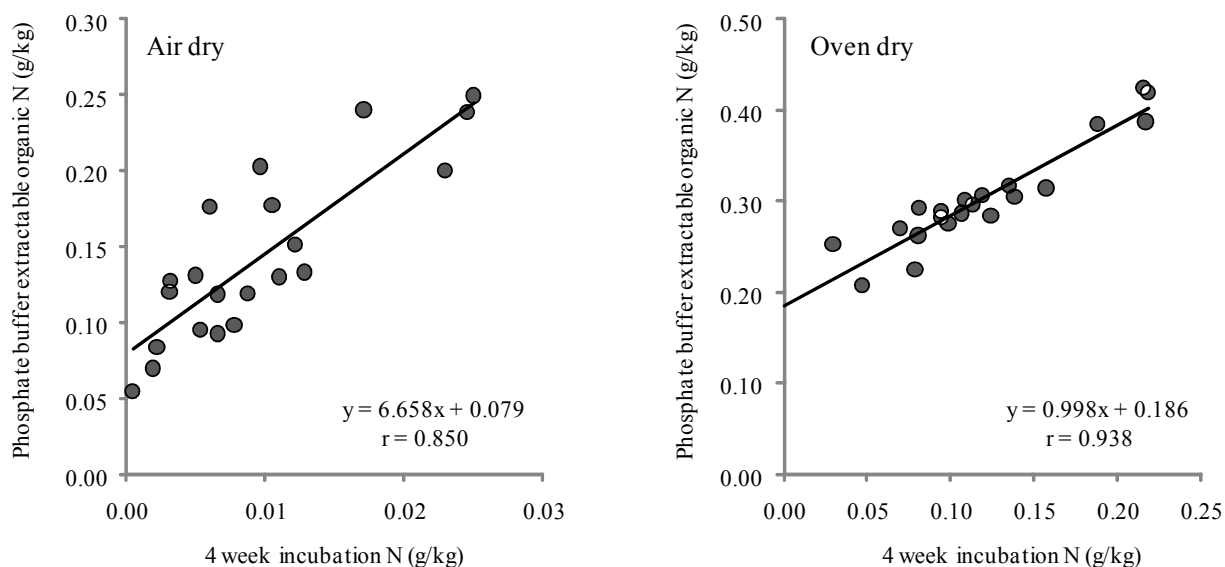


Figure 1. Relationship between phosphate buffer extractable N and 4 week incubation N for air dry (left) or oven dry (160 °C, 2 hour) (right) soil samples of Andosol.

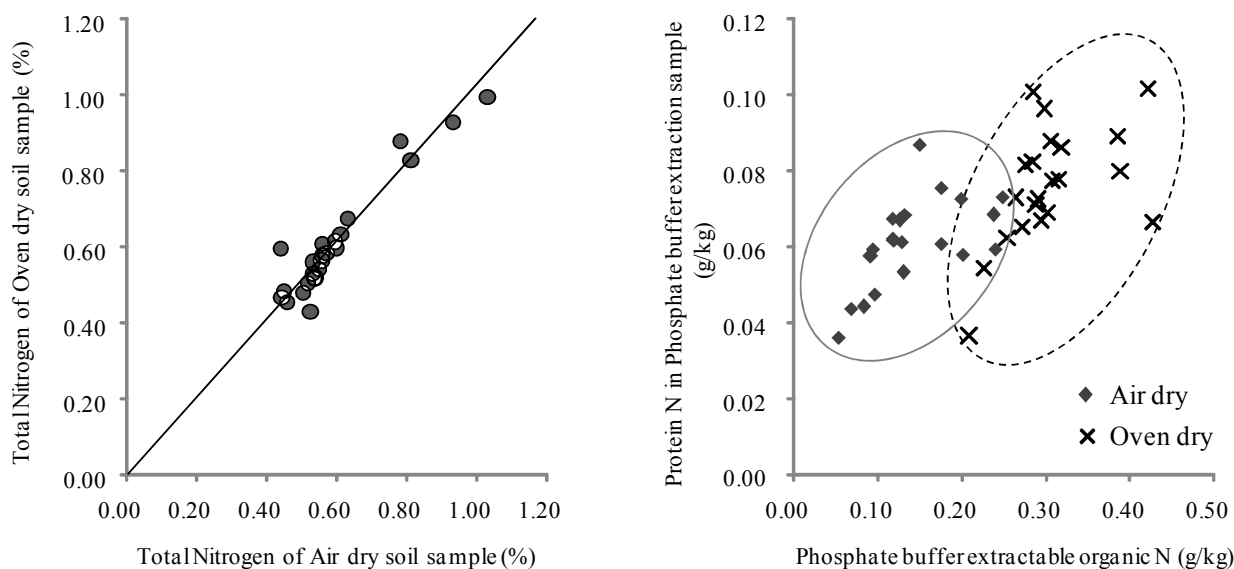


Figure 2. Relationship between oven dry (160 °C, 2 hour) and air dry soil samples for total N (left), and relationship of Protein N in phosphate buffer extraction samples and phosphate buffer extractable N of air dry or oven dry soil samples (right).

Creation of a soil diagnostic formula

In the test field, where inorganic N and the amount of available N (oven dry PB-N) before cultivation differ from each other, the field experiment using Chinese cabbage, corn, and carrot was performed. Chemical fertilizer N was ^{15}N labelled ammonium sulphate (3.07 and 2.09 Atom %) for these experiments. The total amount of N absorption by plants and the amount of ^{15}N absorption by the plants were obtained as a result of the Kjeldahl method and EA-IRMS (Elemental Analysis Isotope Ratio Mass Spectrometry). Multiple linear regression analysis was performed using the following four parameters; the amount of ^{15}N absorption (Y) became the development variable; and the total amount of N absorption of crops (X1), inorganic N (X2), and available N (oven dry PB-N) (X3) became explanatory variables. Consequently, a multiple regression equation significant at the level 1% were obtained.

Chinese cabbage

$$Y = 0.836X1 - (0.339X2 + 0.064X3) \quad R = 0.971 \quad (1)$$

Corn

$$Y = 0.520X1 - (1.310X2 + 0.157X3) \quad R = 0.973 \quad (2)$$

Carrot

$$Y = 0.759X1 - (0.013X2 + 0.440X3) \quad R = 0.930 \quad (3)$$

These were considered as the soil diagnostic formulae for Chinese cabbage, corn and carrot cultivation.

Field examination of using soil diagnostics formula

The experiment was performed in the fields of eight farms. In Chinese cabbage, inorganic N was 14-115 mg/kg and available N was 65-71 mg/kg (Table 1). By using the soil diagnostics formula, the amount of N of a chemical fertilizer was reduced by 20-35 % (Table 1). The yield was 1400-1577 kg/a, and this is the same as commonly found in a farmers fields. In corn, inorganic N was 6-96 mg/kg and available N was 4-83 mg/kg (Table 1). The amount of N of a chemical fertilizer was reduced by 71-90 % by using the soil diagnostics formula (Table 1). The yield was 775-1270 kg/a, and income was reduced compared with normal expectations of a farm. This is because the amount of absorption N was greater than the actual amount of expected absorption N by 0.7-2.1 kg/a. In carrot, inorganic N was 10-26 mg/kg and available N was 54-60 mg/kg (Table 1). By using the soil diagnostics formula, the amount of fertilization N was reduced by 15-24 % (Table 1). The yield is 766-939 kg/a and increased receipts as compared with normal practices of a farm. From these results, it was shown that the amount of N of an appropriate chemical fertilizer is calculable by using a soil diagnostics formula that uses the amount of absorption N, and inorganic N and available N before cultivation.

Table 1. Component of soil diagnostics formula parameters, yield, amount of absorption N and reduction rate of fertilizer N from cultivation experiment of Chinese cabbage, corn and carrot.

	Site No.	Amount of expectation absorption N	Field before cultivation				Examination field of soil diagnosis			
			Inorganic N	Available N	Amount of conventional fertilizer N	Amount of diagnosis fertilizer N	yield	cropping index	Amount of adsorption N	Reduction rate of fertilizer N
			mg/kg	mg/kg	kg/a	kg/a	kg/a	%	kg/a	%
Chinese cabbage (<i>Brassica rapa</i> L.)	1	2.0	115	71	2.0	1.3	1577	108	2.2	35
	2	2.0	42	79	2.0	1.5	1393	100	2.0	25
	3	2.0	14	65	2.0	1.6	1400	105	2.1	20
Corn (<i>Zea mays</i> L.)	4	1.6	96	83	2.5	0.2	1270	105	3.7	90
	5	1.6	6	4	1.8	0.5	775	79	2.3	71
Carrot (<i>Daucus carota</i> L.)	6	2.0	11	60	1.3	1.0	864	112	1.1	20
	7	2.0	26	66	1.3	1.0	766	95	1.3	24
	8	2.0	10	54	1.3	1.1	939	113	1.1	15

Conclusion

The crop management technique that decreases the amount of fertilizer used without yield decline becomes possible by using the soil diagnosis formula, that uses the total amount of N absorption of crops, soil inorganic N, and available N (oven dry PB-N). It is necessary to investigate the absorbed amount of the chemical fertilizer N of each crop to make the soil diagnosis formula. And, it is important to accurately estimate the amount of N absorbed by crops, as they will differ according to each field.

References

- Hartemink AE (1997) Soil fertility decline in some Major Soil Groupings under permanent cropping in Tanga Region, Tanzania. *Geoderma* **75**, 215-229.
- Higuchi M (1981) Characterization of immobilized nitrogen and organic nitrogen extracted with various buffer solution. *Journal of Soil Science and Plant Nutrition* **52**, 481-489. (in Japanese with English summary).
- Matsumoto S, Ae N, Yamagata M (2000) Extraction of mineralizable organic nitrogen from soils by a neutral phosphate buffer solution. *Soil Biology and Biochemistry* **32**, 1293-1299.
- Saito M (1988) Estimation of nitrogen availability indices based on UV absorption of soil extracts. *Journal of Soil Science and Plant Nutrition* **59**, 493-495. (in Japanese with English summary).

Creeping Bentgrass response to a stabilized amine form of nitrogen fertilizer

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Abstract

PiNT+potassium (PiNT+K) is a newly developed amine form of N fertilizer that is stabilized by reaction with the potassium cation. The influence of PiNT+K and an analog fertilizer (KNO₃ and NH₄NO₃) on the quality of creeping bentgrass were compared at different N rates (0, 25, 37.5 and 50 kg N/ha). At the same N rate, the normalized difference vegetation index (NDVI) of the PiNT+K treatments was 2-3% higher than the analog treatments, while the dark green color index (DGCI) was 4-7% higher. Fertilizer burn (osmotic desiccation) was observed on plots treated with the analog fertilizer, but treatments with PiNT+K appeared safe from osmotic desiccation even at high N rates. The application N rate of 37.5 kg N/ha of PiNT+K outperformed the analog fertilizer at 50 kg N/ha when the quality of creeping bentgrass, turfgrass management, and N use efficiency were considered. The PiNT+K treatment yielded better quality as measured by NDVI and DGCI, yielded similar above-ground biomass, and had less unused N (N application – N uptake) in comparison to the analog fertilizer.

Key Words

Nitrogen, amine, turfgrass, fertilizer.

Introduction

Nitrogen fertility is an important component of putting green management. Under optimal growing conditions and nutrient sufficiency, no other plant nutrient has as significant an influence on turfgrass canopy color and vigor (Waddington *et al.* 1978), root-to-shoot ratios (Schlossberg and Karnok 2001), or disease susceptibility (Davis and Dernoeden 2002). The N fertilizers can be divided into categories of fast- and slow-release sources (Guillard and Kopp 2004; Schlossberg and Schmidt 2007). Use of quick-release fertilizers is appropriate for correcting N deficiency, but may also yield greater biomass and have greater leaching. Less frequent applications can safely be made to turfgrass using slow-release N fertilizers. Slow release fertilizers steadily supply available nutrients and minimize risks of leaching and osmotic tissue desiccation (Carrow *et al.* 2001). The effect of these two sources of N on turfgrass quality and NO₃ leaching has been investigated in previous studies (e.g., Engelsjord and Singh 1997; Guillard and Kopp 2004; Saha *et al.* 2007). PiNT+potassium (PiNT+K) (Plant Impact Inc., Preston, UK) is a uniquely controlled uptake nitrogen /potassium fertilizer formulated to support plant quality, yield, root promotion and stress tolerance. The liquid PiNT+K fertilizer contains 13.7% stabilized NH₂, 1.3% NO₃, 7% K₂O, and 0.17% patented Speedo chemistry (Plant Impact Inc., Preston, UK). This unique manufacturing chemistry keeps the N in the amine form to support a better growth habit - more reproductive development growth of specialty horticultural crops (e.g., flowers and fruit) without over-stimulating vegetative growth. However, there is no published scientific information on the effect of PiNT+K on turf growth. The objective of this study was to compare shoot growth, nutrient concentration, and color of a creeping bentgrass (*Penn A-1/A-4*) putting green in response to typical nitrogen fertilizer application rates using PiNT+K versus a soluble analog fertilizer (prepared using KNO₃ and NH₄NO₃).

Materials and methods

A fertility trial was conducted on a Penn A1/A4 creeping bentgrass (*Agrostis stolonifera* L.) putting green, established in 2005 to a sand/sphagnum peat moss root zone maintained within the Penn State University Joseph Valentine Turfgrass Research Center, University Park, PA, USA. Plots (0.9 x 2.1 m) were mowed 6-7 times weekly at a height of 3.1 mm (1/8"). Clippings were collected for N content analysis and were not returned to the putting greens. Potable irrigation was applied to prevent plant wilt, but fertilizer treatments were not watered in. Replicates of six fertilizer treatments (and an untreated control) were randomly assigned to each of four blocks. An analog fertilizer (13-0-7) was formulated using KNO₃ and NH₄NO₃ for comparison to PiNT+K. On 20 July 2009, PiNT+K and analog fertilizers were applied to deliver 25, 37.5, or 50 kg N/ha in an 815 L/ha spray volume using a CO₂-pressurized, single nozzle wand (Tee-Jet TP11008E, Spraying Systems Co., Wheaton, IL). Concomitant K₂O deliveries from either fertilizer were 11.7 or 23.3 kg

K/ha, respectively. Observed N deficiencies in plots of both fertilizers receiving the 25 kg N/ha rate required reapplication of 25 kg N on 10 August, for a total application of 50 kg N/ha.

Two to five days per week, duplicate simultaneous measures of 660– and 850–nm light reflectance from the canopy of each bentgrass putting green plot were recorded using an ambient light-excluding FieldScout TCM-500 turfgrass chlorophyll meter (Spectrum Technologies Inc., Plainfield, IL). Reflectance data were used to calculate normalized differential vegetative indices (NDVI). Duplicate measures of percent green, red, and blue canopy reflectance collected by a color meter (FieldScout TCM-500-RGB) were converted to hue, saturation, and brightness levels to determine dark green color index (DGCI; Karcher and Richardson 2003). The week following fertilizer applications, above-ground biomass was collected every 6-7 d. Plant tissue was dried at 70°C, ground to pass 1-mm sieve, and analyzed for total Kjeldahl nitrogen (TKN). Treatment effects on NDVI, DGCI, above-ground biomass, TKN, and N uptake were determined by ANOVA.

Results and discussion

NDVI and DGCI

The NDVI and DGCI, derived from multispectral data, have been widely used as an assessment of the overall health and quality of turfgrass (e.g., Fitz-Rodriguez and Choi 2002; Karcher and Richardson 2003; Xiong *et al.* 2007). Higher NDVI and DGCI were observed with PiNT+K compared to the analog N fertilizer (Figure 1). Generally at a given N rate, NDVI with PiNT+K was 2-3% greater than with the analog, while the DGCI was 4-7% greater. At 25 kg N/ha, NDVI was greater with PiNT+K ($p<0.1$) than with the analog on 13 of 24 measurement dates (data not shown), while at 37.5 and 50 kg N/ha, NDVI was greater with PiNT+K on 18 and 11 dates, respectively. Similarly, at 25 kg N/ha, DGCI was greater with PiNT+K on 10 of 22 dates, while at 37.5 and 50 kg N/ha, DGCI was greater with PiNT+K on 10 and 8 measurement dates, respectively. Differences in NDVI and DGCI between PiNT+K at 25 or 37.5 kg N/ha and analog at 50 kg N/ha were not significant ($p<0.05$) on most measurement dates.

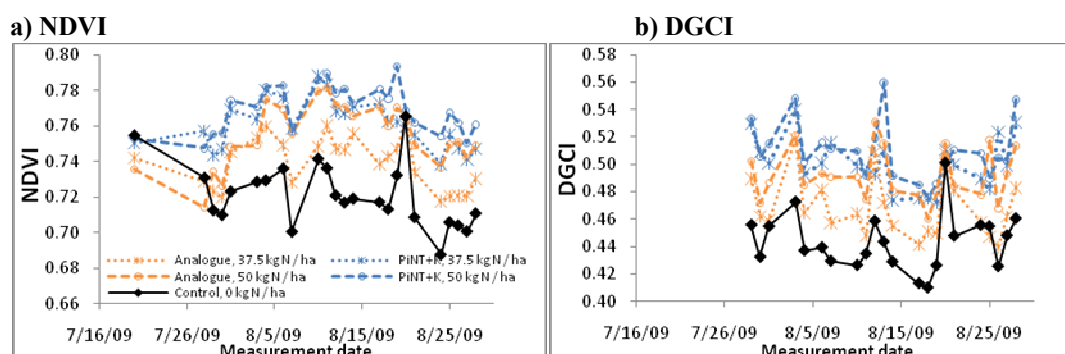


Figure 1. Temporal variations of a) NDVI and b) DGCI with different treatments.

Fertilizer burn (osmotic desiccation) is a concern for turfgrass management. In Figure 2, treatments with PiNT+K appeared rather safe from osmotic desiccation even at high N rates. However, treatments with the analogue fertilizer, especially at high N rates, showed osmotic desiccation. The deviations of NDVI and DGCI of the PiNT+K treatments from the control were positive and significantly ($p<0.05$) greater than those of the analogue.

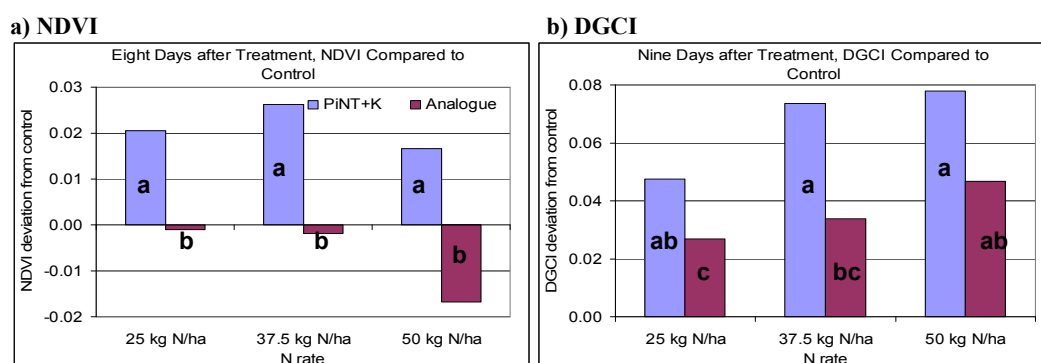
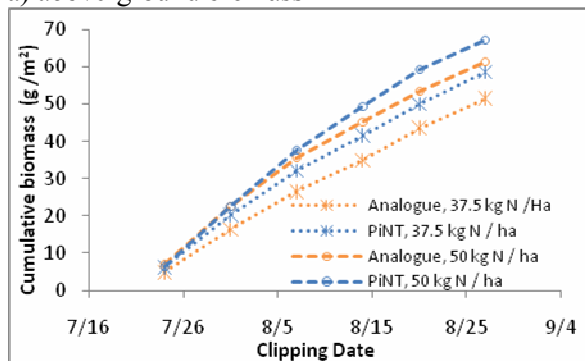


Figure 2. The deviations of a) NDVI and b) DGCI of fertilized treatments from control. In each graphic, bars with the same letter are not significantly different at $p<0.05$.

Above-ground biomass produced with PiNT+K at 37.5 kg N/ha was similar to that produced with the analog at 50 kg N/ha (Figure 3a; Table 1). By the end of the trial (8/27/2009), there was no significant difference in cumulative N uptake between PiNT+K at 37.5 kg N/ha and the analog at 50 kg N/ha (Figure 3b and Table 1). However, there was significantly less unused N (N applied - N uptake) with PiNT+K at 37.5 kg N/ha compared to the analog at 50 kg N/ha (Table 2).

Above-ground biomass and N uptake

a) above-ground biomass



b) N uptake

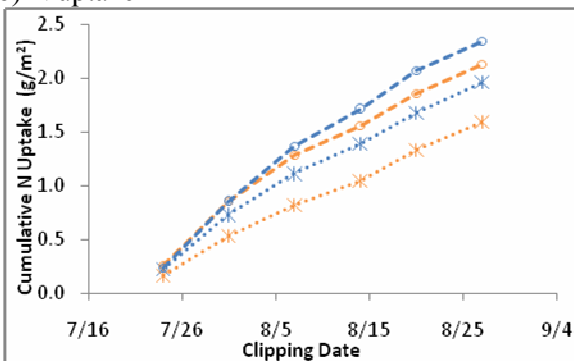


Figure 3. Cumulative curves of a) above-ground biomass and b) N uptake of creeping bentgrass with treatments (Trt) of PiNT+K and the analog at 37.5, and 50 kg N/ha.

Table 1. Comparing the cumulative above-ground biomass and N uptake on 8/7/2009 and 8/27/2009 of PiNT+K and analog treatments. For cumulative above-ground biomass or N uptake on each date, numbers with the same letter are not significant at $p < 0.05$.

N rate (kg/ha)	Cumulative above-ground biomass (g/m ²)				Cumulative N uptake on (kg/ha)			
	8/7/2009		8/27/2009		8/7/2009		8/27/2009	
	PiNT+K	Analog	PiNT+K	Analog	PiNT+K	Analog	PiNT+K	Analog
37.5	32.2a	26.5b	58.5a	51.5b	11.1b	8.2b	19.6a	15.9b
50	37.6a	35.7a	67.1a	61.4a	13.7a	12.9a	23.4a	21.3a

Table 2. Comparison of N uptakes and N applied in creeping bentgrass treated with PiNT+K and analog at 37.5 and 50 kg N/ha. The unused N remaining is the difference between N applied and N uptake. At each day, numbers with the same letter are not significant at $p < 0.05$.

Treatment	N applied (kg N/ha)	Unused N on 8/7/2009 (kg N/ha)	Unused N on 8/27/2009 (kg N/ha)
Analog, 37.5 kg N/ha	37.5	29.3ab	21.6ab
PiNT+K, 37.5 kg N/ha	37.5	26.4b	17.9b
Analog, 50 kg N/ha	50	37.2a	28.7a
PiNT+K, 50 kg N/ha	50	36.3a	26.6a

Conclusions

The responses of creeping bentgrass growth to PiNT+K and an analog N (KNO_3 and NH_4NO_3) were compared in this study. Greater quality of creeping bentgrass (greater NDVI and DGCI) was observed with PiNT+K at all rates. PiNT+K treatments did not exhibit osmotic desiccation. The 37.5 kg N/ha rate of PiNT+K was comparable to the analog at 50 kg N/ha in terms of vegetative growth and N uptake; unused N was significantly less, indicating greater N use efficiency of PiNT+K over the period of this trial. Using PiNT+K at the lower rate resulted in similar NDVI and DGCI measurements as the analog with greater N rates while producing similar or slightly less above-ground biomass, both of which are desirable characteristics for maintaining healthy and fast putting greens.

References

- Carrow RN, Waddington DV, Rieke PE (2001) 'Turfgrass soil fertility and chemical problems: Assessment and management'. (J. Wiley and Sons: Hoboken, NJ).
- Davis JG, Dernoeden PH (2002) Dollar spot severity, tissue nitrogen, and soil microbial activity in bentgrass as influenced by nitrogen source. *Crop Science* **42**, 480–488.
- Engelsjord ME, Singh, BR (1997) Effects of slow-release fertilizers on growth and on uptake and leaching of nutrients in Kentucky bluegrass turfs established on sand-based root zones. *Canadian Journal of Plant Science* **77**, 433–444.

- Fitz-Rodriguez E, Choi CY (2002) Monitoring turfgrass quality using multispectral radiometry. *Transactions of ASAE* **45**, 865-871.
- Guillard K, Kopp KL (2004) Nitrogen fertilizer form and associated nitrate leaching from cool-season lawn turf. *Journal of Environmental Quality* **33**, 1822-1827.
- Karcher DE, Richardson MD (2003) Quantifying turfgrass color using digital image analysis. *Crop Science* **43**, 943-951.
- Saha SK, Treholm LE, Unruh JB (2007) Effect of fertilizer source on nitrate leaching and St. Augustinegrass turfgrass quality. *Horticulture Science* **42**, 1478-1481.
- Schlossberg MJ, Karnok KJ (2001) Root and shoot performance of three creeping bentgrass cultivars as affected by nitrogen fertility. *Journal of Plant Nutrition* **24**, 535-548.
- Schlossberg MJ, Schmidt JP (2007) Influence of Nitrogen rate and form on quality of putting greens cohabitated by creeping bentgrass and annual bluegrass. *Agronomy Journal* **99**, 99-106.
- Waddington DV, Turner TR, Duich JM, Moberg EL (1978) Effect of fertilization on Pennncross creeping bentgrass. *Agronomy Journal* **70**, 713-718.
- Xiong X, Bell GE, Solie JB, Smith MW, Martin B (2007) Bermudagrass seasonal responses to nitrogen fertilization and irrigation detected using optical sensing. *Crop Science* **47**, 1603-1610.

Deep placement of lime nitrogen promotes nitrogen fixation and seed yield of soybean with efficient utilization rates.

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Abstract

Average soybean yield is low compared with the potential yield. N is derived from three sources; N₂ fixation, soil N, and fertilizer N. A heavy supply of N fertilizer often depresses nodule development and N₂ fixation activity, which sometimes results in the reduction of seed yield. We developed a new fertilization technique for soybean cultivation by deep placement (at 20 cm depth from the soil surface) of slow release N fertilizers, coated urea and lime nitrogen (calcium cyanamide) at the rate of 100kgN/ha. These treatments consistently promoted seed yield compared with conventional cultivation in the field with various types of soils. Fertilizer N was efficiently used to supplement N during seed filling stage without concomitant depression of nitrogen fixation and nodule growth. In this research, the effect of deep placement of lime nitrogen was evaluated using a rhizobox to investigate the distribution of nodules and roots. The result showed that deep placement of lime nitrogen promoted nodulation in the upper layers of the root system at pod filling stage. The fate of lime nitrogen in soil was investigated by incubation test, and it was suggested that cyanamide is rapidly degraded in 2 weeks, but nitrification was depressed for a long period.

Key Words

Lime nitrogen, deep placement, nitrogen fixation, nodule, soybean, cyanamide.

Introduction

Annual world production of soybean seeds increased up to 220 million t in 2007. The highest yield in Japan was recorded 7.8 t/ha, and the yield is around 6 t/ha under good climatic conditions (Takahashi *et al.* 1991). However, the world average seed yield is 2.3 t/ha, and Japanese average is only 1.7 t/ha. Soybean seeds contain a large amount of protein N and the total amount of N assimilated in a plant is highly correlated with the soybean seed yield. One t of soybean seed requires about 70-90 kg N, which is about four times more than in the case of one t of rice grain production. Soybean plants assimilate the N from three sources; N derived from symbiotic N₂ fixation by root nodules (Ndfa), absorbed N from soil mineralized N (Ndfs), and N from fertilizer when applied (Ndff). For the maximum seed yield of soybean, it is necessary to use both N₂ fixation and absorbed N from roots (Harper 1987). Sole N₂ fixation is often insufficient to support vigorous growth, which results in the reduction of seed yield. On the other hand, a heavy supply of N fertilizer often depresses nodule development and N₂ fixation activity and induces nodule senescence, which sometimes results in the reduction of seed yield. Therefore, no nitrogen fertilizer is applied for soybean cultivation or only a small amount of N fertilizer is applied as a starter N to promote initial growth in Japan.

A polymer coated controlled release N fertilizer (commercial name LP in Japan or MEISTER outside Japan) has been invented by Fujita and co-workers (1999). This type of fertilizer has a spherical shape about 3 mm diameter with 50-60 µm coat thickness, which consists of polyolefin (polyethylene), ethylene vinyl acetate and talc mineral. The N release rate from coated urea is temperature dependent and not affected by other chemicals, physical and biological conditions in soil, and the release pattern can be predicted as a function of temperature and time period after application. Since the release of N from the fertilizer meets the plant N demand, and the fertilizer efficiency (recovery rate of N in plants from fertilizer) is high, the use of coated urea can reduce the environmental problems by decreasing nitrate accumulation and leaching in the soil. Furthermore, the use of coated urea saves the labour of farmers by eliminating a top dressing to supply N during later stage.

Takahashi *et al.* (1991,1992,1993,1994,1999) developed a new fertilization technique for soybean by deep placement of coated urea. They applied coated urea by deep placement at 20 cm depth from a soil surface using a fertilizer injector. They used CU-100 in which 80 % of N is released in 100 days in water at 25 C. Fertilizer experiments were carried out from years 1989 to 1991 in the field, which had been converted from a paddy rice field in the previous year. The seed yield was from 10 to 23 % higher in deep placement than the control treatments. The promotion of leaf growth and retardation of leaf senescence were observed during the maturing stage by deep placement of coated urea. The seed yield was very high about 6 t/ha in deep placement in 1990 due to the favorable climatic conditions compared with years 1989 and 1991. The absorption efficiency of fertilizer N determined by ^{15}N labeled fertilizers was calculated from recovery of ^{15}N in the shoots at R7 stage. In 1990, the absorption efficiency from the deep placement of CU-100 was 62 %, which was much higher than the top dressing of CU-70 (33 %) and basal application of ammonium sulfate (9 %). Recently, Tewari *et al.* (2002,2003,2004ab, 2005,2006ab) investigated the effects of deep placement of lime nitrogen (calcium cyanamide, CaCN_2) in comparison with coated urea (CU-100). The fertilizer experiments were combined with new inoculation method of bradyrhizobia using a paper pot inoculation method. All the experiment was carried out in 2001 in three different sites in Niigata Prefecture: a rotated paddy field in Niigata Agricultural Experiment Station, a first cropping field after reclamation with the dressing of mountain soil without indigenous bradyrhizobia and a sandy dune field of Faculty of Agriculture in Niigata University. The effects of the application of different fertilizers, urea, coated urea and lime nitrogen on the growth, N accumulation and N_2 fixation activity of soybean plants were compared.

Lime nitrogen contains about 60 % of calcium cyanamide (CaCN_2) with calcium oxide and carbon, and the N content is about 20-23%. It corresponds chemically and physiologically to a basic fertilizer, and it neutralizes the soil acidity. Calcium cyanamide is converted to urea in soil, which is again degraded into NH_3 and CO_2 . Dicyandiamide contained in lime nitrogen or formed during the degradation of calcium cyanamide in soil retards the oxidation of NH_3 to NO_3^- , since it is a potent nitrification inhibitor. Therefore, the ammonium produced by CaCN_2 decomposition persists for a longer period of time and the nitrate concentration remains low in soil. It is expected that the inhibition of nodulation and of the N_2 fixation activity may be alleviated by low level of nitrate accumulation in the soil. In addition, this fertilizer exerts some hormonal effects on plants and is used for controlling soil diseases caused by bacteria and fungi.

The effect of deep placement of ammonium sulfate (AS), urea (U), coated urea (CU) and lime nitrogen (LN) on the N origin was investigated by ^{15}N dilution method (Tewari *et al.* 2005). Deep placement of ^{15}N labeled fertilizers (100kgN/ha) were applied in the converted paddy field in the same field as above (Nagaoka). Soybean cv. Enrei and the non-nodulated isogenic line En1282 were planted. Whole plants were sampled at maturing stage, and ^{15}N abundance and N concentration in each part were analyzed. The evaluation of Nd_{fa}, Nd_{fs} and Nd_{ff} was conducted by ^{15}N dilution method using En1282 as a reference plant. The value of the seed weight per plant of Enrei was highest in LN (73g) followed by CU (63g), U (47g), AS (37g) and control without deep placement (26g). The value of Nd_{fa} estimated by ^{15}N dilution method was higher in LN (3.6g) and CU (2.8g) than in U (2.3g) and AS (2.3g) treatments. The recovery rate of fertilizer N was higher in LN (43%) and CU (36%) than U (21%) and AS (21%) treatments. These results confirmed that deep placement of both LN and CU is effective to improve soybean growth and seed yield by promoting nitrogen fixation by root nodules.

To investigate the utilization of N from LN compared with CU, soybean plants were periodically sampled with deep placement of ^{15}N labelled LN and CU. The N absorption was initially lower with LN than CU at the R3 and R5 stages, but the absorption from LN exceeded CU at R7 stage. The recovery rate was 70% in LN and 61% in CU. The daily N_2 fixation activity and N absorption rate was calculated by a simple relative ureide method. In all the treatments, the higher N_2 fixation activity was found during R3 and R5 stages with LN (630 mg/m².d), CU (616 mg/m².d), and Cont (464 mg/m².d) treatments. The seed yield per plant was 37g (Cont), 67g (CU), and 71g (LN).

The yield increase by deep placement of CU-100 and CaCN_2 were mainly due to the increase in the pod number per plant. The deep placement of CU-100 as well as CaCN_2 contributed to the increase of the total node number in the branches and the pod number per node, leading to the increase of seed yield. This condition prevents flower and pod shedding due to nutrient competition or stress during the transition from the vegetative to the reproductive growth, which may account for the good yield obtained with both the CaCN_2 and CU-100 treatments.

Methods

The effect of deep placement of lime nitrogen on soybean nodulation

The experiment was conducted in a rotated paddy field of Niigata Agricultural Research Institute, Nagaoka. Conventional basal dressing of ammonium sulfate (16 kgN/ha), fused magnesium phosphate (60 kgP₂O₅/ha) and potassium chloride (80 kgK₂O/ha) fertilizers were mixed in the plow layer (0-13 cm depth) of the experimental plot. A soybean plant was cultivated in the center of the wooden box (45 cm x 4.5cm x 30 cm Length, Width, Depth) filled with the field soil. The boxes were buried in the field. The soil is a Fine-Textured Gray Lowland soil. Average chemical properties of the soil were as follows: texture; CL, pH(H₂O); 6.6, CEC; 28.8 (cmol(+)/kg), total carbon content; 10.9 g/kg, total N content; 1.02 g/kg, amount of mineralized N determined by the incubation of air dry soil under upland conditions for 4 weeks at 30 C; 47 mg/kg. Two fertilizer treatments were conducted as follows: Control; no additional fertilizer. Deep placement of lime nitrogen; basal deep placement (20cm depth from a soil surface) of lime nitrogen (1.12gN/plant) in the box. At R1 (initial flowering stage) and R5 (pod filling stage) (Fher 1971), rhizoboxes were sampled. The soil profile was separated by 5 cm x 5cm blocks, and soils were washed out. The roots and nodules were dried and the dry weight was measured.

Changes in lime nitrogen incubated with field soil

To investigate the fate of lime nitrogen in soil, 250 mg of lime nitrogen was mixed with 10.3 g of air dry soil and incubated at 25 C for 0, 2, 4, 6, 8 weeks after water concentration was adjusted at 60% of maximum water holding capacity. Then soil was extracted by 2% acetic acid, and cyanamide concentration was determined by amino acid analyzer (Nagumo *et al.* 2009). Dicyandiamide was determined by capillary electrophoresis. Ammonia was analyzed by Indophenol method. Urea was determined by Indophenol analysis of ammonia after it was hydrolysed by urease. Nitrate was analysed by Cataldo method (Cataldo *et al.* 1974).

Results

The effect of deep placement of lime nitrogen on soybean nodulation

At R1 stage, total nodule weight of the plants treated with deep placement of lime nitrogen was 0.57g/plant and lower than the control nodule weight 0.73g/plant. The nodule distribution was not different between deep placement of lime nitrogen and control treatment. On the other hand, at R5, the total nodule dry weight of deep placement of lime nitrogen was 1.17g/plant and much higher than that in control plants 0.73g/plant. The nodule weight in the upper layer of soil in lime nitrogen treatment was higher than control treatment. This observation supported the estimation of promotion of nitrogen fixation by deep placement of lime nitrogen by relative ureide method. The dry weight of the shoots was also higher in deep placement of lime nitrogen (37g/plant) compared with control plants (28g/plant) at R5 stage. From these results, it was confirmed that deep placement of lime nitrogen provides the N in the reproductive stage, and it promotes nodule growth and nitrogen fixation through vigorous photosynthetic activity of the leaves.

Changes in lime nitrogen incubated with field soil

At the start of incubation, most N was in the form of cyanamide. However, the cyanamide concentration decreased to 0.66% of original concentration after 2 weeks of incubation, and it was very rapidly decomposed. At 4,6,8 weeks of incubation, the concentration of cyanamide was 0.45%, 0.38% and 0.28 % of original concentration. The concentration of urea-N increased at 2 weeks to 18 % of total N, then decreased to 1.4% at 8 weeks. The concentration of ammonia-N increased gradually to 1%, 6%, 12%, 12%, and 18% at 0, 2, 4, 6, 8 weeks. During the incubation period up to 8 weeks, the nitrate-N concentration was 0.2% of total added lime nitrogen, and the nitrification was completely depressed. The concentration of dicyandiamide was very high up to 60% of lime nitrogen N under these experimental conditions.

Conclusion

For maintaining agricultural production and protecting the environment, it is crucial important that efficient use of N fertilizer. The forms, rate, time and place of fertilizer application are important to provide N for the demand of various crops grown under different soil and climatic conditions. For soybean cultivation, deep placement of lime nitrogen promoted plant growth and seed yield through promotion of nitrogen fixation, especially after initial flowering stage. In this study, the promotive effect of deep placement of lime nitrogen was confirmed by rhizobox cultivation. Also, by soil incubation test of lime nitrogen, the nitrification was completely depressed until 8 weeks, and it was in association to the accumulation of dicyandiamide.

References

- Cataldo KA, Schrader LE, Youngs VL (1974) Analysis by digestion and colorimetric assay of total nitrogen in plant tissues high in nitrate. *Crop Sci.* **14**, 854-856.
- Fehr WR, Caviness CE, Burmood DT, Pennington JS (1971) Stage development description for soybean *Glycine max* (L.) Merrill. *Crop Sci.*, **11**, 929-931.
- Fujita T, Shoji S (1999) Meister: Controlled release fertilizer, Ed. Shoji S, Konno Printing Company Ltd.
- Harper, JE (1987) Nitrogen metabolism. In Soybeans: Improvement, Production and Uses, second edition, Agronomy Monograph. **16**, 497-533.
- Nagumo Y, Tanaka K, Tewari K, Tsuchida T, Honma T, Ohtake N, Sueyoshi Kuni, Takahashi Y, Ohshima T (2009) Rapid quantification of cyanamide by ultra-high-pressure liquid chromatography in fertilizer, soil or plant samples. *J. Chromatography A*. **1216**, 5614-5618.
- Takahashi Y, Chinushi T, Nagumo Y, Nakano T, Ohshima T (1991) Effect of deep placement of controlled release nitrogen fertilizer (coated urea) on growth, yield and nitrogen fixation of soybean plants. *Soil Sci. Plant Nutr.* **37**, 223-231.
- Takahashi Y, Chinushi T, Nakano T, Ohshima T (1992) Evaluation of N₂ fixation and N absorption activity by relative ureide method in field grown soybean plants with deep placement of coated urea. *Soil Sci. Plant Nutr.* **38**, 699-708.
- Takahashi Y, Chinushi T, Ohshima T (1993) Quantitative estimation of N₂ fixation and absorption rate in field grown soybean plants by relative ureide method. *Bull. Fac. Agric. Niigata Univ.* **45**, 91-105.
- Takahashi Y, Chinushi T, Nakano T, Ohshima T (1994) Yield components of soybean plants with deep placement of N fertilizer, related to high productivity. *J. Niigata Agric. Exp. Stn.* **40**, 7-15.
- Takahashi Y, Ohshima T (1999) Technique for deep placement of coated urea fertilizer in soybean cultivation. *JARQ* **33**, 235-242.
- Tewari K, Suganuma T, Fujikake H, Ohtake N, Sueyoshi K, Takahashi Y, Ohshima T (2002) Effect of deep placement of calcium cyanamide, coated urea, and urea on soybean (*Glycine max* (L.) Merr.) seed yield in relation to different inoculation methods. *Soil Sci. Plant Nutr.* **48**, 855-863.
- Tewari K, Minagawa R, Suganuma T, Fujikake H, Ohtake N, Sueyoshi K, Takahashi Y, Tsuchida T, Ohshima T (2003) Effect of deep placement of slow release nitrogen fertilizers and inoculation of Bradyrhizobia on the first cropping of soybean in the field dressed with mountain soil. *Jpn. J. Soil Sci. Plant Nutr.* **74**, 183-189.
- Tewari K, Suganuma T, Fujikake H, Ohtake N, Sueyoshi K, Takahashi Y, Ohshima T (2004a) Effect of deep placement of N fertilizers and different inoculation methods of bradyrhizobia on growth, N₂ fixation activity and N absorption rate of field grown soybean plants. *J. of Agronomy and Crop Science* **190**, 46-58.
- Tewari K, Onda M, Ito S, Yamazaki A, Fujikake H, Ohtake N, Sueyoshi K, Takahashi Y, Ohshima T (2004 b) Effect of placement of urea and coated urea on yield and quality of soybean (*Glycine max* (L.).) seed. *Soil Sci. Plant Nutr.* **50**, 1245-1254.
- Tewari K, Onda M, Ito S, Yamazaki A, Fujikake H, Ohtake N, Sueyoshi K, Takahashi Y, Ohshima T, (2005) analysis of promotive effect of deep placement of slow release N fertilizers on growth and seed yield of soybean. *Soil Sci. Plant Nutr.* **51**, 501-512.
- Tewari K, Onda M, Ito S, Yamazaki A, Fujikake H, Ohtake N, Sueyoshi K, Takahashi Y, Nagumo Y, Tsuchida T, and Ohshima T (2006a) Comparison of the depth of placement of lime nitrogen on growth, N₂ fixation activity, seed yield and quality of soybean (*Glycine max* (L.) Merr.) plants. *Soil Sci. Plant Nutr.* **52**, 453-463
- Tewari K, Onda M, Ito S, Yamazaki A, Fujikake H, Ohtake N, Sueyoshi K, Takahashi Y, Nagumo Y, Tsuchida T, Ohshima T (2006b) Effect of deep placement of slow release fertilizer (lime nitrogen) applied at different rates on growth, N₂ fixation and yield of soybean (*Glycine max* [L.] Merr.). *J. of Agronomy and Crop Science* **192**, 417-426.

Denitrification bioreactors for agricultural drainage nitrate treatment in New Zealand

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Abstract

Nitrate loadings from agricultural drainage causes serious water quality concerns in many parts of the world including the US Midwest and New Zealand. Targeted nutrient management is necessary to increase the environmental sustainability of agricultural systems in these locations. Denitrification bioreactors for reducing nitrate loads in agricultural drainage are one such option that has shown potential as a nutrient removal technology in the US. Denitrification bioreactors consist of carbon-filled (wood media) trenches through which drainage is routed allowing enhancement of denitrification. Work presented here provides a background on denitrification bioreactor design, nitrate removal effectiveness, and possible application to drainage systems in New Zealand's intensively grazed pasture lands.

Key Words

Denitrification, water quality, nitrate, drainage, nutrient management

Introduction

Nitrate loadings from agricultural drainage affect surface waters worldwide. In the US Midwest, this nitrate pollution has been implicated as a major cause of the hypoxic zone in the Gulf of Mexico (Rabalais *et al.* 1996; USGS 2000). Reducing nitrate loadings in the Mississippi River Basin leading to the Gulf of Mexico is a pressing water quality issue in the United States (USEPA 2007). Similarly, nitrate pollution in agricultural drainage has caused concern in New Zealand in recent years. Much of this degradation in water quality in New Zealand can be attributed to the rapid expansion of the dairy industry over the past two decades. In particular, nitrate enrichment of surface waters is a consequence of dairying on artificially drained grazing land (Monaghan *et al.* 2002; Houlbrooke *et al.* 2004).

In the US Midwest, fields that are artificially drained with subsurface tile drains are predominantly cropped with corn and soybeans (Dinnes *et al.* 2002). Drainage patterns in the upper Midwest (Iowa, Minnesota, Illinois) typically consist of precipitation-dependent high flows in the spring and summer (February-July) (Gentry *et al.* 2009) trailing off in the late summer around harvest time (Gentry *et al.* 2000; Randall 2004). Drain flow in winter (December-January) is uncommon in many northern Midwestern soils because there is little precipitation and the soil may be frozen (Kalita *et al.* 2006). In the Midwest, drainage systems are typically designed for flows of 9.5 to 12 mm/d (ISU Extension 2008). In contrast, New Zealand's climate results in the majority of the drainage volume occurring in the high rainfall winter months (June – August) (Monaghan *et al.* 2002) with drainage occurring as discrete events with relatively high short-term flow rates of up to 4 mm/hr (Magesan, *et al.* 1995).

Typical NO₃-N concentrations in tile drainage in the US Midwest range from 10 to 20 mg NO₃-N/L (Mirek 2001; Kalita *et al.* 2006) with maximum values of 52 mg NO₃-N/L (Gentry *et al.* 2000). These concentrations provide annual loadings mostly in the range of 25-30 kg NO₃-N/ha (Kalita *et al.* 2006), though loadings can be as high as 65-70 kg NO₃-N/ha (Kladivko *et al.* 1991; Jaynes *et al.* 1999). The majority of the N load in drainage from New Zealand's intensive pastoral land also occurs as NO₃-N at average concentrations and annual N loadings similar to the values reported for the Midwest (Monaghan *et al.* 2002; Houlbrooke *et al.* 2004).

Subsurface drainage systems act as short-circuiting, conduits for nitrate loadings to surface waters, reducing the opportunity for denitrification to occur in the soil (Mirek 2001; Kellman 2005). Several options have been proposed to reduce these nitrate loadings including increased use of wetlands and cover crops and better nutrient management and crop rotations (Dinnes *et al.* 2002; Jaynes *et al.* 2004). However, regardless of better management strategies, nitrate concentrations in drainage waters can still exceed the drinking water

standard because of the variability of agricultural systems (Kladivko *et al.* 2004). In New Zealand, the main source of nitrate leaching from intensively grazed pastoral soils is cattle urine spots (Di and Cameron 2002a). There are a limited number of mitigation strategies, such as decreased grazing times or use of nitrification inhibitors, that have been shown to reduce nitrate leaching from grazed soils (de Klein and Ledgard 2001; Di and Cameron 2002b). However, provision of a wide range of options for reducing nitrate leaching is important to enable farmers to choose a strategy that will work well for their farming system.

Denitrification bioreactors could provide an important new option for treatment of waters from artificial drainage systems under pasture in New Zealand. Recently, denitrification treatments have been successful in reducing nitrate in groundwater in New Zealand and for treating septic effluent in Canada (Schipper and Vojvodic-Vukovic 2000; Schipper *et al.* 2005; Robertson and Cherry 1995). Edge-of-field nitrate removal from agricultural drainage can be enhanced with the use of subsurface, carbon-filled excavations through which drainage is routed (i.e. a denitrification bioreactor). This treatment system has proven effective in the US Midwest, where nitrate concentration reductions within bioreactors can be very high (upwards of 60%) (Appleford *et al.* 2008; Jaynes *et al.* 2008). For agricultural bioreactors, wood media is recommended as it provides good longevity, good performance and is readily available (Cooke *et al.* 2001; Greenan *et al.* 2006). Bioreactors can be incorporated into grassed buffers and occupy an area that is typically 0.1% of the drainage treatment area (drainage areas of 10 to 40 ha).

Currently in the US Midwest, denitrification bioreactors are designed to treat up to twenty percent of the peak drainage flow rate at between four and eight hours of retention. It would be too costly to build bioreactors capable of treating 100% of the peak estimated drainage flow rate (Van Driel *et al.* 2006a). Installing denitrification bioreactors into artificial drainage systems in New Zealand will be a unique challenge given their very high flow rates (Magesan *et al.* 2004). It may be possible to treat only a relatively small percentage of the drainage water (i.e. significantly less than the 20% of peak flow rate achieved for the Midwest situation) (Table 1). Where practicable, containment ponds may be constructed to stabilize flow rates, and thereby allow treatment of a greater portion of the drainage event. The type of bioreactor fill media, temperature and the required retention time to allow denitrifiers to become competitive in New Zealand systems may also differ from what has been previously found in the US Midwest.

Nitrate removal rates from denitrification systems have been consistently high especially in comparison with wetland systems (Table 2). Robertson and Merkley (2009) and Van Driel *et al.* (2006a) found bioreactor removal rates could be forty times greater and an order of magnitude greater than wetland rates, respectively.

Conclusion

Denitrification bioreactors have shown potential to reduce agricultural drainage nitrate loads in the US Midwest and, therefore, their application as a mitigation strategy in New Zealand is also worth investigation. *In situ* trials are necessary to test this technology under New Zealand's climate and field conditions before it can be offered as a viable edge-of-field nitrate reduction option to landowners.

Table 1. Possible design differences for Midwestern and New Zealand denitrification bioreactors using the current Iowa design model based on peak flow rate and required retention time.

	Area	Peak Flow	Proportion of peak	Volume of bioreactor material
	drained (ha)	Rate (mm/hr)	flow rate treated	required (m ³)
Midwest USA	16	0.5	20%	266
Manawatu – NZ	5	4	10%	338

Table 2. Nitrate removal rates for denitrification treatment systems reported in literature.

Reference	System description	Location	Nitrate Removal Rate	
			System Volume	System Surface Area
Schipper and Vojvodic-Vukovic 2000	Sawdust flow-through wall for groundwater	Cambridge, New Zealand	0.11-0.43 g N/m ³ /d	N/A
Schipper <i>et al.</i> 2005	Sawdust flow-through wall for groundwater	Cambridge, New Zealand	1.4 g N/m ³ /d	N/A
Fahrner 2002 thesis cited in Schipper <i>et al.</i> 2005	Sawdust flow-through wall for groundwater	Busselton, Australia	15 g N/m ³ /d	N/A
Jaynes <i>et al.</i> 2008	Flow-through woodchip wall between crop rows	Iowa, USA	0.62 g N/m ³ /day	N/A
Van Driel <i>et al.</i> 2006a	Fine and coarse wood media agricultural drainage reactor	Ontario, Canada	2.3 g N/m ³ /d	2.5 g N/m ² /d
Van Driel <i>et al.</i> 2006b	Fine wood media, riparian groundwater treatment	Ontario, Canada	1.2-5 g N/m ³ /d	0.7 to 3.5 g N/m ² /d
Christianson ,2009	Pilot scale woodchip bioreactors	Iowa, USA	3.8-5.6 g N/m ³ /d	1.5-3.4 g N/m ² /d
Xue <i>et al.</i> 1999	Constructed wetland (drainage water)	Illinois, USA	N/A	0.05-0.28 g N/m ² /d
Hernandez and Mitsch 2007	Constructed wetland (river water)	Ohio, USA	N/A	0.005-0.043 g N/m ² /d

References

- Appleford JM, Rodriguez LF, Cooke RAC, Zhang Y, Kent AD, Zilles J (2008) Characterization of Microorganisms Contributing to Denitrification in Tile Drain Biofilters in Illinois. 2008 ASABE Annual International Meeting, Providence, RI.
- Christianson LE (2009) Unpublished data.
- Cooke RA, Doheny AM, Hirschi MC (2001) Bio-reactors for edge of field treatment of tile outflow. 2001 ASABE Annual International Meeting, Sacramento, CA.
- Di HJ, Cameron KC (2002a) Nitrate leaching in temperate agroecosystems: Sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems* **46**, 237-256.
- Di HJ, Cameron KC (2002b) The use of a nitrification inhibitor, dicyandiamide (DCD), to decrease nitrate leaching and nitrous oxide emissions in a simulated grazed and irrigated grassland. *Soil Use and Management* **18**, 395-403.
- Dinnes DL, Karlen DL, Jaynes DB, Kaspar TC, Hatfield JL, Colvin TS, Cambardella CA (2002) Nitrogen management strategies to reduce nitrate leaching in tile-drained midwestern soils. *Agronomy Journal*, **94**(1), 153-171.
- de Klein CAM, Ledgard SF (2001) An analysis of environmental and economic implications of nil and restricted grazing systems designed to reduce nitrate leaching from New Zealand dairy farms. I. Nitrogen losses. *New Zealand Journal of Agricultural Research* **44**, 201-215.
- Gentry LE, David MB, Below FE, Royer TV, McIsaac GF (2009) Nitrogen Mass Balance of a Tile-drained Agricultural Watershed in East-Central Illinois. *J. of Envir. Quality* **38**(5), 1841-1847.
- Gentry LE, David MB, Smith-Starks KM, Kovacic DA (2000) Nitrogen fertilizer and herbicide transport from tile drained fields. *Journal of Environmental Quality* **29**(1), 232-240.
- Greenan CM, Moorman TB, Kaspar TC, Parkin TB, Jaynes DB (2006) Comparing carbon substrates for denitrification of subsurface drainage water. *Journal of Envir. Quality* **35**(3), 824-829.
- Hernandez ME, Mitsch WJ (2007) Denitrification in created riverine wetlands: Influence of hydrology and season. *Ecological Engineering* **30**(1), 78-88.
- Houlbrooke D, Hanly J, Horne D, Hedley M (2004) Nitrogen losses in artificial drainage and surface runoff from pasture following grazing by dairy cattle. SuperSoil 2004: 3rd Australian New Zealand Soils Conference, University of Sydney, Australia.

- ISU Extension (2008) Iowa Drainage Guide. Iowa State University Extension Special Report 13.
- Jaynes DB, Hatfield JL, Meek DW (1999) Water quality in Walnut Creek Watershed: Herbicides and nitrate in surface waters. *Journal of Environmental Quality* **28**, 45-59.
- Jaynes DB, Kaspar TC, Moorman TB, Parkin TB (2004) Potential methods for reducing nitrate losses in artificially drained fields. American Society of Agricultural Engineers, St. Joseph, MI 49085-9659, United States, Sacramento, CA, United States, 59-69.
- Jaynes DB, Kaspar TC, Moorman TB, Parkin TB (2008) In situ bioreactors and deep drain-pipe installation to reduce nitrate losses in artificially drained fields. *J. of Envir. Qual.* **37**(2), 429-436.
- Kalita PK, Algoazany AS, Mitchell JK, Cooke RAC, Hirschi MC (2006) Subsurface water quality from a flat tile-drained watershed in Illinois, USA. *Agriculture, Ecosystems and Envir.*, 115.
- Kellman LM (2005) A study of tile drain nitrate -15N values as a tool for assessing nitrate sources in an agricultural region. *Nutrient Cycling in Agroecosystems*, 71.
- Kladivko EJ, Frankenberger JR, Jaynes DB, Meek DW, Jenkinson BJ, Fausey NR (2004) Nitrate leaching to subsurface drains as affected by drain spacing and changes in crop production system. *Journal of Environmental Quality* **33**(5), 1803-1813.
- Kladivko EJ, Van Scoyoc GE, Monke EJ, Oates, K. M., and Pask, W. (1991) Pesticide and Nutrient Movement into Subsurface Tile Drains on a Silt Loam Soil in Indiana. *J. of Env. Qual.* **20**(1), 264-270.
- Magesan GN, White RE, Scotter DR (1995) The influence of flow rate on the concentration of indigenous and applied solutes in mole-pipe drain effluent. *Journal of Hydrology* **172**, 23-30.
- Mirek ST (2001) Effect of nitrogen fertilizer management and seasonality of tile flow on nitrate leaching through tile drains. University of Illinois at Urbana-Champaign, Urbana-Champaign.
- Monaghan RM, Paton RJ, Drewery JJ (2002) Nitrogen and Phosphorus Losses in Mole and Tile Drainage from a Cattle-Grazed Pasture in Eastern Southland. *New Zealand J. of Ag. Res.* **45**, 197-205.
- Rabalais NN, Wiseman WJ, Turner RE, Sen Gupta BK, Dortch Q (1996) Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. *Estuaries and Coasts* **19**(2), 386-407.
- Randall, G. W. (2004) Subsurface Drain Flow Characteristics during a 15-Year Period in Minnesota. Drainage VIII Proceedings, ASAE Publication Number 701P0304, Sacramento, California.
- Robertson WD, Cherry JA (1995) In situ denitrification of septic-system nitrate using reactive porous media barriers: Field trials. *Ground Water* **33**(1), 99-111.
- Robertson WD, Merkley LC (2009) In-stream bioreactor for agricultural nitrate treatment. *Journal of Environmental Quality* **38**(1), 230-237.
- Schipper LA, Vojvodic-Vukovic M (2000) Nitrate removal from groundwater and denitrification rates in a porous treatment wall amended with sawdust. *Ecological Engineering* **14**(3), 269-278.
- Schipper LA, Barkle GF, Vojvodic-Vukovic M (2005) Maximum rates of nitrate removal in a denitrification wall. *Journal of Environmental Quality* **34**(4), 1270-1276.
- USEPA (2007) Hypoxia in the Northern Gulf of Mexico: An update by the EPA Science Advisory Board. U.S. Environmental Protection Agency Science Advisory Board, Washington, D.C. EPA-SAB-08-003.
- USGS (2000) Nitrogen in the Mississippi Basin - Estimating Sources and Predicting Flux to the Gulf of Mexico. United States Geological Survey. USGS Fact Sheet 135-00.
- Van Driel PW, Robertson WD, Merkley LC (2006a) Denitrification of agricultural drainage using wood-based reactors. *Transactions of the ASABE* **49**(2), 565-573.
- Van Driel PW, Robertson WD, Merkley LC (2006b) Upflow reactors for riparian zone denitrification. *Journal of Environmental Quality* **35**(2), 412-420.
- Xue Y, Kovacic DA, David MB, Gentry LE, Mulvaney RL, Lindau CW (1999) In Situ Measurements of Denitrification in Constructed Wetlands. *Journal of Envir. Quality* **28**(1), 263-269.

Development of a fertiliser optimisation technique using multi-nutrient factorial trials and leaf tissue nutrient analysis in commercial oil palm plantations

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Abstract

Ensuring fertilisers are applied at optimal rates makes economic sense as well as minimising the chance of excess nutrients causing environmental damage. A technique has been developed which uses information from factorial fertiliser trials and nearby commercial plantings of oil palm to determine the optimal economic application rates of three nutrients simultaneously, thus accounting for interactions. The technique is based on a spreadsheet application that can be analysed as often as required in response to climate variation, oil price, and fertiliser costs. It also allows for scenario testing by allowing changes in these costs and prices.

Key Words

Fertiliser response, regression models, economic optimum, nitrogen, potassium, phosphorus

Introduction

Optimising fertiliser use to obtain optimum economic yield usually has the added benefit of ensuring that excess fertiliser is not available for loss to the environment. Often factorial fertiliser trials are used where there is the likelihood of multiple nutrient deficiencies (Corley and Tinker 2003, p342). Such trials can also be used to determine a critical leaf nutrient concentration (CLNC) for diagnosis of plant nutrient status.

Webb (2009) developed a conceptual framework for a novel way of using factorial trials to determine optimum economic fertiliser rates for two nutrients in the oil palm industry; based on work by Wilkie and Foster (1989). The advantage of this technique is that it allows use of all of the trial data rather than just those few data, for each nutrient being tested, that are available at the optimum rates of the other nutrients – a common requirement for determining maximum yield. By having these trials near commercial blocks of palms, they can be used on an annual basis to make ‘basal’ (standard annual application) economically optimum fertiliser decisions in relation to fertiliser costs and oil prices. In addition to this, leaf nutrient analysis in commercial blocks, can be used to make ‘corrective’ (based on leaf analysis) fertiliser decisions; without the usual issues of soil type, plant age, climate etc, which limit the usefulness/versatility of the common usage of CLNCs (Smith and Loneragan 1997). For example, leaf nutrient concentration in oil palm fronds can vary greatly from month to month (Foster 2003) and these variations may not be consistent from year to year.

This paper extends the framework of Webb (2009) from determining the economically optimum fertiliser rates for two nutrients, to the economically optimum for three nutrients, simultaneously.

Concept

The conceptual framework underpinning this approach is given in Webb (2009) for two nutrients, so only a brief description will be given here. The nutrient requirement (for each nutrient of interest) is made up of a ‘basal’ amount that should be added each year to maintain optimum growth plus, if necessary, a ‘corrective’ amount to alleviate any deficiencies (as determined by leaf analysis). The key processes are:

1. Use field trials and multiple linear regression to produce a yield response surface to the three fertilisers applied. Convert this yield to a crop value (\$/ha).
2. Subtract fertiliser costs, re-analyse the response surface to obtain an optimum economic yield and determine the rate of application of each of the three fertiliser-nutrients to obtain that yield – this determines the basal fertiliser-nutrient requirements that should be added each year.
3. Analyse leaf tissues from the trial and nearby commercial blocks at the same time.
 - a. Use the trial data (on a representative soil type) to produce a leaf-nutrient concentration response surface (for each nutrient) to the three fertiliser-nutrients applied.
 - b. For each leaf-nutrient determine its leaf concentration at the rates of the three fertiliser-nutrient application which gave optimum economic yield (from 2 above). This determines the target leaf nutrient concentration (TLNC) for each leaf-nutrient.
 - c. Use commercial leaf sampling data and the surface produced in 3a above to determine the ‘equivalent’ fertiliser-nutrient application rate for each leaf-nutrient.

4. Use the difference between the optimum fertiliser rate and the 'equivalent' fertiliser rate to calculate the amount of fertiliser required to raise the leaf-nutrient concentration to the TLNC – this determines the corrective fertiliser requirement.

Theoretical framework

Modelling profit in response to fertiliser-nutrient application

Again, a detailed theoretical framework is given in Webb (2009) for two nutrients, so only that which specifically relates to three nutrients is given here.

Yield (t/ha) can be described by the equation:

$$Yield = a + bN + cN^2 + dK + eK^2 + fP + gP^2 + hNK + iKP + jPN \quad (1)$$

Where N, K, and P represent fertiliser-N, -K and -P respectively; NK, KP, PN represent the interactions and $a-j$ are the parameters to be estimated by multiple linear regression (see Webb 2009 for details). This is converted to a crop value (\$/ha) by multiplying by u , the unit value of the crop (\$/t). Thus, crop value is:

$$CropValue = u[a + bN + cN^2 + dK + eK^2 + fP + gP^2 + hNK + iKP + jPN] \quad (2)$$

Profit is calculated by subtracting the cost of fertiliser application (\$/ha). Thus

$$Profit = u[a + bN + cN^2 + dK + eK^2 + fP + gP^2 + hNK - iKP + jPN] - rN - sK - tP \quad (3)$$

Where r , s , and t are the cost (\$/ha) of applying N, K, and P fertiliser respectively.

To find the point of maximum profit, the derivatives of the equations are solved for the point at which slope is zero. For two nutrients this is simple (see Webb 2009), but for three these equations become complicated and cumbersome. A simpler way is to use matrix operations. Differentiation of equation (3), equating to zero, and rearranging gives:

$$2cN + hK + jP = r/u - b \quad \text{with respect to N} \quad (4)$$

$$hN + 2eK + iP = s/u - d \quad \text{with respect to K} \quad (5)$$

$$jN + iK + 2gP = t/u - f \quad \text{with respect to P} \quad (6)$$

In matrix form this can be written:
$$\begin{bmatrix} 2c & h & j & r/u - b \\ h & 2e & i & s/u - d \\ j & i & 2g & t/u - f \end{bmatrix}$$
. By using Gauss-Jordan row operations

(Kalmanson and Kenschaft 1978, p96-101), this is transformed to
$$\begin{bmatrix} 1 & 0 & 0 & N \\ 0 & 1 & 0 & K \\ 0 & 0 & 1 & P \end{bmatrix}$$

where the N, K, and P now represent the application rate which give maximum profit. These thus become the basal rate of fertiliser application resulting in maximum profit.

Modelling leaf nutrient concentrations in response fertiliser-nutrient application

Tissue nutrient concentrations are also fitted to a multiple linear regression of quadratic equations thus:

$$[n] = a + bN + cN^2 + dK + eK^2 + fP + gP^2 + hNK + iKP + jPN \quad (7)$$

Where $[n]$ represent tissue N concentration, and $a-j$ are the parameters to be estimated. By substituting N, K, and P with the values that give maximum profit, the corresponding value of leaf N concentration is determined; this is the TLNC. TLNCs for K and P are calculated similarly. It is now necessary to calculate the "nutrient-fertiliser equivalent" of the plantation leaf samples. This is fertiliser-nutrient application rate that would be expected to produce the observed tissue-nutrient concentration. This is determined by solving the quadratic for the above equation (7) rewritten as:

$$0 = cN^2 + (b + hK + jP)N + (a + dK + eK^2 + fP + gP^2 + iKP - [n]) \quad (8)$$

where $[n]$ is the commercial plantation leaf N concentration. This can also be written as

$$0 = Ax^2 + Bx + C \quad (9)$$

where x is the fertiliser-N application rate, $A = c$, $B = (b + hK + jP)$, and

$C = a + dK + eK^2 + fP + gP^2 + iKP - [n]$. The solution to this quadratic is

$$x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}, \text{ thus using the original parameters:} \quad (10)$$

$$\text{Fertiliser-N rate} = \frac{-(b + hK + jP) \pm \sqrt{(b + hK + jP)^2 - 4c(a + dK + eK^2 + fP + gP^2 + iKP - [n])}}{2c} \quad (11)$$

Where K is fertiliser-K and P is fertiliser-P, both at optimum rate. Each of these solutions will give two answers but the answer chosen will be the smallest positive. The difference between the fertiliser-N calculated above (11) and the optimum fertiliser-N, represents the corrective fertiliser-N and should be added to the basal fertiliser-N rate. Corrective fertilizer-K and fertilizer-P are calculated in the same way.

In Practice

Brief description of field trial

Full details of the trial are available in PNG Oil palm Research Association Inc. (2005). Trial 209 was set up as a factorial combination of three rates of N (0.42, 0.84, 1.68 kg/palm/yr), three rates of K (0, 1, 2 kg/palm/yr), three rates of P (0, 0.8, 1.6 kg/palm/yr), and three rates of Mg (0, 0.68, 1.36 kg/palm/yr). Yields of fresh fruit bunches (FFB) were averaged for 2003-2005 (Table 1). Treatments N, K, and P main effects produced significant differences ($p < 0.05$) but Mg did not; thus results for the Mg treatment were averaged. Leaf tissues were collected and analysed by standard methods (see Webb 2009).

Table 1. Effects* of N, K, and P treatments on average yield of fresh fruit bunches (FFB) from 2003-2005.

Rate level (see text for actual rates)	FFB (t/ha/yr)		
	N	K	P
1	27.0	27.3	28.2
2	29.9	30.3	30.0
3	31.7	30.9	30.4

* Significance levels were $p = 0.001, 0.013, 0.001$ for main effects of N, K, and P, respectively.

Analysis of the full data set by multiple linear regression provides the parameter estimates (p value) as follows: a, 20.12 (<0.001); b, 10.24 (0.003); c, -3.31 (0.03); d, 2.61 (0.04); e, -0.91 (0.109); f, 5.77 (<0.001); g, -2.06 (0.01); h, 0.48 (0.41); i, -0.12 (0.80); j, -0.23 (0.75), which, when substituted into (1), predict yield.

Results

All the necessary calculations have been incorporated into a spreadsheet. Using the above parameters and equations, it can be seen that the optimum economic fertiliser application rates (kg/palm/yr) are 1.03 N, 0.23 P (Figure 1) and 0.52 K (not shown) under set conditions of oil price, oil extraction rate and fertiliser cost. These parameters can be varied as prices change or to test various scenarios; some results of which are shown in Table 2. The spreadsheet also provides the recommendation for each commercial block, which includes the basal and corrective rates for each of the three fertiliser-nutrients. As the variable parameters change (oil price fertiliser cost, oil extraction rate), so the recommendations for basal and corrective fertiliser also change in response to the new economic optimum.

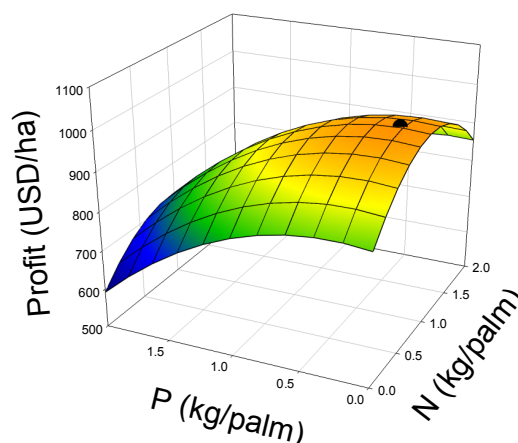


Figure 1. Relationship between profit, and N and P fertiliser.

The scenario testing described above shows that, as expected, with increasing oil price and extraction rates, profit and fertiliser use increases (Table 2). However, surprisingly, at low oil price and high fertiliser cost, profits increase. Inspection of data shows that this is because fertiliser use was reduced to zero in some cases. This clearly reflects the annual nature of the analysis and does not take into account longer term sustainability issues. Thus, sensible decisions based on long term sustainability issues should override short term accounting decisions. Indeed, a sensible approach would be add fertiliser-nutrients at rates which at least replace the nutrient removed in the harvested product.

Table 2. Effect of oil price, oil extraction rate and fertiliser costs on annual profit and fertiliser use.

Oil Price (USD/t)	450		900	
Oil extraction rate (%)	22	25	22	25
<i>Profit (USD/ha)</i>				
Fertiliser Cost 1 *	1364	1594	4146	4840
Fertiliser Cost 2	1534	1762	3857	4495
<i>Fertiliser use (kg/palm)**</i>				
Fertiliser Cost 1	7.7 (62:14:24)	9.2 (57:16:27)	14.1 (48:19:33)	14.5 (47:19:34)
Fertiliser Cost 2	2.0 (1:0:0)	2.9 (1:0:0)	10.8 (53:17:30)	11.7 (51:18:31)

* Fertiliser costs (USD/t) are: ammonium sulphate 300, KCl 400, TSP 300, for "Cost 1" and double that for "Cost 2".

** Ratio of nutrient mix (N:K:P) in parentheses.

Conclusion

Using multiple linear regression (in this case, for three nutrients), large scale, multi-level, multi-factor fertiliser trials can be used effectively to maximise profit while minimising fertiliser use, and thus minimising the potential for negative off-site impacts. This technique allows for effects of individual nutrients as well as their interactions. These can be responsive to changes in fertiliser cost and oil price and thus used as a decision support/scenario tool for 'basal' fertiliser application. When used in conjunction with nearby commercial planting (on the same soil type) with regular leaf nutrient analysis, they can also be used to determine 'corrective' fertiliser application rates to counteract nutrient deficiencies that may occur. Although developed for oil palm, this approach could easily be adapted to other perennial crops.

Acknowledgements

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References

- Corley RHV, Tinker PB (2003) The oil palm, 4th edn. Blackwell Science, Oxford.
- Foster HL (2003) Assessment of oil palm fertiliser requirements. In 'Oil palm: management for larger and sustainable yields' (Eds. Fairhurst T, Härdter R), pp 231-257. Potash & Phosphate Institute/Potash & Phosphate Institute of Canada and International Potash Institute, Singapore.
- Kalmanson K, Kenschaft PC (1978) Mathematics: a practical approach. Worth Publishers, Inc: New York.
- PNG Oil Palm Research Association Inc. (2005) Annual Research Report – 2005. Dami Research Station, PO Box 97, Kimbe, West New Britain Province, Papua New Guinea, Ph +675 985 4009, Fx +675 985 4040, eMail enquiries@pngopra.org.pg.
- Smith FW, Loneragan JF (1997) Interpretation of plant analysis: concepts and principles. In 'Plant analysis: An interpretation manual' (Eds. Reuter DJ, Robinson JB), pp 3-33. CSIRO Publishing, Collingwood.
- Webb MJ (2009) A conceptual framework for determining economically optimal fertiliser use in oil palm plantations with factorial fertiliser trials. *Nutrient Cycling in Agroecosystems* **83**, 163-178.
- Wilkie AS, Foster HL (1989) Oil palm response to fertilisers in Papua New Guinea. In *PORIM International Palm Oil Development Conference*, pp. 395-405.

Effect of long-term fertilization on organic matter, total nitrogen and microbe characteristic of black soil

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Abstract

The changes in black soil organic matter, total nitrogen and microbe characteristics were studied for a long-term fertilization experiment which has been on-going for 27 years. Results showed that the treatment of organic manure plus chemical fertilizer increased the content of soil organic matter and total nitrogen, while the no fertilizer treatment had the lowest contents. Soil pH declined under long-term chemical fertilizer and the addition of organic manure decreased pH slowly as well. The addition of chemical fertilizer increased the number of cellulose utilizing bacteria. The number of N utilizing microbes increased significantly under the addition of organic manure plus chemical fertilizer with the number of ammonifying bacteria being most affected.

Key Words

Long-term experiment, black soil, organic matter, microbe characteristic.

Introduction

Black soil has many characteristics, such as deep depth of humus, incompact texture, higher natural fertility, higher content of clay and so on. The black soil area in northeast of China, as one of three big black soil area in world, was the important production base of commodity grain in China. Soil fertility properties had changed after reclamation, the soil natural fertility had a descending trend in great areas, soil nutrient and microorganism properties etc. also had changed (Chen *et al.* 1984; Huang *et al.* 2005; Li *et al.* 2006; Wang *et al.* 2008). Long-term fixed experiment at important sites and measures to understand each factor and their interaction effect in farm ecosystems and the productivity of land, was useful to illuminate trends. Some mechanisms of soil fertility and the interaction effects among factors could only be recognized rightly after 10 years (Xu *et al.* 2006; Wu *et al.* 2008). This the long-term fixed experiment on black soil to study soil organic matter, total nitrogen and microbe characteristics under long-term different fertilization, tried to reveal the evolution rule of soil fertility and microorganism characteristics, to provide a basis for improving fertility and the quality of black soil.

Methods

Location and treatments

Soil samples were collected from a long-term experiment station in April, 2005. This station was established in 1979, since its establishment, this station adopted crop rotation: wheat-soybean-corn, the basic soil chemical properties are in Table 1. We selected four treatments and amounts of fertilizer are listed in Table 2. Soybean was planted in 2005. Soil samples were divided into two parts, one part air-dry for soil nutrient measurement, the other part kept cold for microbe analysis.

Methods

- 1) Nutrient: organic matter and total nitrogen were measured by Vario Elementar, Germany; soil pH was measured in a 1:5 soil to water solution using a glass electrode (Lu 1991).
- 2) Microorganisms: the numbers of ammonifying bacteria, aerobic bacteria for cellulose decomposition, aerobic nitrogen-fixing bacteria were measured by a diluted flat method. Nitrobacteria, denitrifying bacteria, anaerobic bacteria of cellulose decomposition, anaerobic nitrogen-fixing bacteria were analyzed by a MPN method (Lab of Microorganism 1985).

Table 1. The basic soil chemical properties (0-20cm).

O.M (g/kg)	Total N (g/kg)	Total P (g/kg)	Total K (g/kg)	pH
26.7	1.47	1.07	25.16	7.22

Table 2. The treatments and fertilizer application rates.

Treatment	Fertilizer application rates		
	Soybean stubble	Corn stubble	Wheat stubble
CK	0	0	0
NPK	N 75 kg/ha, P ₂ O ₅ 150 kg/ha, K ₂ O 75 kg/ha	N 150 kg/ha, P ₂ O ₅ 75 kg/ha, K ₂ O 75 kg/ha	
M	N 75 kg/ha (manure: about 18600 kg/ha) every three years	0	0
MNPK	N 75 kg/ha, P ₂ O ₅ 150 kg/ha, K ₂ O 75 kg/ha+ N 75 kg/ha	N 150 kg/ha, P ₂ O ₅ 75 kg/ha, K ₂ O 75 kg/ha	

(Note: nitrogen fertilizer-urea, phosphorus fertilizer-superphosphate and monoammonia phosphate, potassium fertilizer-potassium sulphate).

Results

Soil organic matter and total nitrogen were the important indexes of soil fertility (Mäder *et al.* 2002). Results (Figure 1) showed that different long-term fertilizations had significant effects on soil organic matter content, the content followed: M>MNPK>NPK>CK. Long-term no fertilizer decreased the content of soil nitrogen and fertilization increased the soil nutrient content, especially the organic manure plus chemical fertilizer (MNPK). The pH had effects on status, transformation and availability of soil nutrients. Long-term chemical fertilization (NPK) decreased the pH value. Compared to chemical fertilizer organic manure (M) treatment the value of pH decreased slowly, which would avoid aggravating soil acidification.

The bacteria of cellulose decomposition took major part in utilizing microbe C (Zhang *et al.* 2001), after incubation, the cellulose decomposition was mostly by fungi in this study (Figure 2). The results also found that fertilization increased the numbers of bacteria of cellulose decomposition and numbers of fungi of cellulose decomposition in four treatments (CK, M, NPK, MNPK) were 1.64, 2.76, 4.66 and 1.91×10⁴ g-l dry soil respectively. The amounts of aerobic bacteria and anaerobic bacteria under NPK treatment were higher than for other treatments.

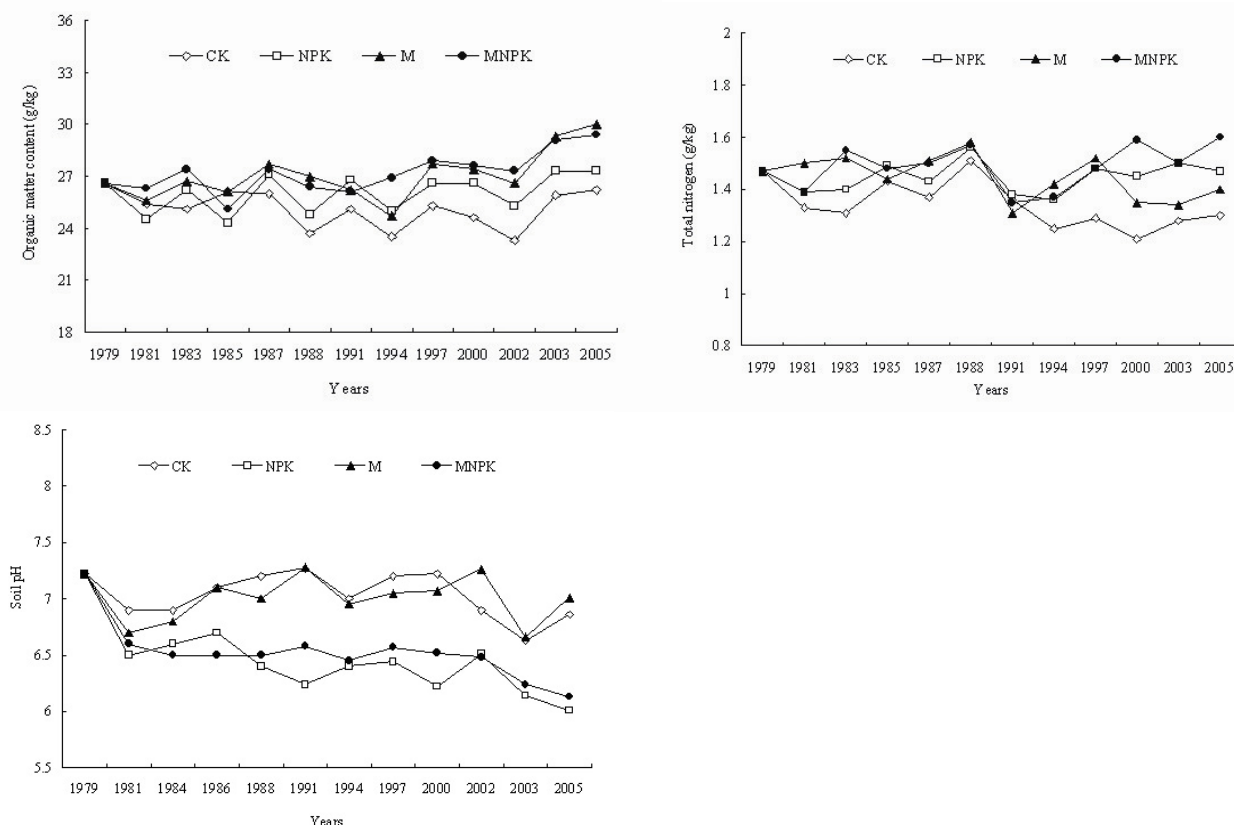


Figure 1. Changes of organic matter and total nitrogen content, pH value in black soil under different long-term fertilizations (1979-2005).

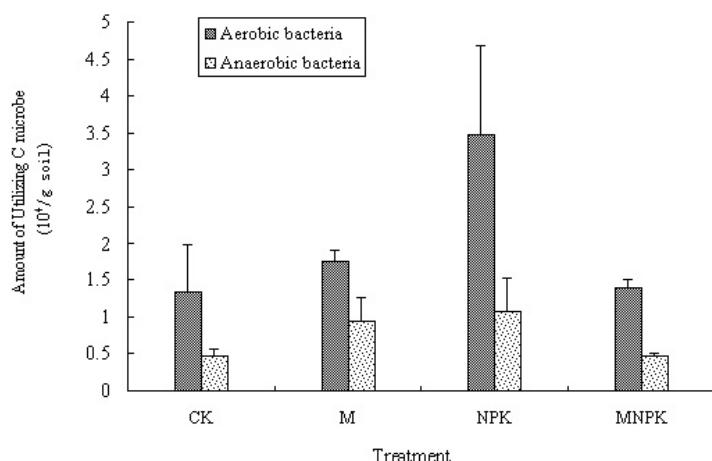


Figure 2. Number of C utilizing microbes in black soil under different long-term fertilizations.

Results (Figure 3) show that in N utilizing microbes, the numbers followed: ammonifying bacteria>nitrogen-fixing bacteria>denitrifying bacteria>nitrobacteria, the MNPK treatment had the most ammonifying bacteria, nitrogen-fixing bacteria and denitrifying bacteria, which accounted for 54.79%, 7.74% and 4.25% of total number of bacteria, the number of nitrobacteria was most for the NPK treatment, accounting for 1.82% of the total number of bacteria. The MNPK treatment increased the number of N utilizing microbes significantly more than the NPK treatment.

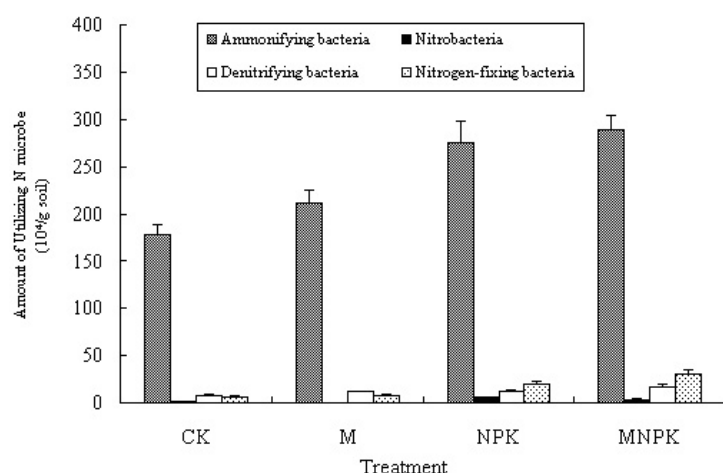


Figure 3. Number of N utilizing microbes in black soil under different long-term fertilizations.

Conclusion

1. Long-term organic manure plus chemical fertilizer treatment increased contents of soil organic matter and total nitrogen, which was very important for improving soil fertility. The pH value declined under long-term chemical fertilizer treatment, whereas organic manure treatment could slow down soil acidification.
2. The number of ammonifying bacteria was largest for N utilizing microbes, it accounted for 55% of the total number of bacteria, the number of nitrobacteria was the least. MNPK treatment increased the number of N utilizing microbes significantly. The bacteria for cellulose decomposition took a major part in utilizing microbes C; NPK treatment had the most number of these bacteria.

References

- Chen EF, Zhou LK, Wu GY(1984) Study on the Essence of soil fertility II. Black soil. *Acta Pedologica Sinica* **21**, 229-237.
- Huan J, Zhang HL, Fu WY, Ma B, Li X, Wang AW (2005) Analysis of the Changing Characteristics of the Soil Fertilities in the Black Soil Area of Northeast China. *Chinese Journal of Soil Science* **36**, 659-663.
- Wang XB, Wu YY, Deng L (2008) Approaches to Black Soil Degeneration in Northeast China. *Resources and Industries* **10**, 81-83.
- Li FP, Li JY, Xu ZX (2006) The Status Quo of Black Soil Degradation and Water and Soil Loss in Northeast China. *Research of Soil and Water Conservation* **13**, 50-54.

- Xu MG, Liang GQ, Zhang FD (2006) 'Changes of Soil Fertility in China'. (China Agricultural Science and Technology Press Publishing: Beijing).
- Wu CY, Chen Y, Yang SM, Wang JY (2008) Evolution of soil fertility in a long-term fertilizer experiment. *Acta Agriculturae Zhejiangensis* **20**, 353-357.
- Lu RK (1991) 'Analysis Methods of Soil Agricultural Chemistry'. (China Agriculture Press Publishing: Beijing).
- Lab of Microorganism, Institute of Soil Science, Chinese Academy of Sciences (1985) 'Study methods of soil microorganism'. (Science Press Publishing: Beijing).
- Mäder P, Bach AF, Dubois D (2002) Soil fertility and biodiversity in organic farming. *Science* **293**, 1694-1697.
- Zhang CB, Jin ZX, Li JM (2001) Diversity of bacterial physiological groups and microbial flora in the soil of eight forest types of Tiantai Mountain, Zhejiang. *Chinese Biodiversity* **9**, 385-388.

Effect of nitrogen fertilization timing on juice and bagasse quality of sweet sorghum for biofuel production

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Abstract

Sweet sorghum biomass yields vary with hybrid, however, there is limited research done on how varying levels of nitrogen interacts with hybrids in affecting biomass produced and quality of extracted juice. The objective is to determine the forage and ethanol yield and quality under different Nitrogen management conditions. A three year experiment was initiated at Dupuy farm, Gene Autry, OK in 2008. The treatments are two varieties (Topper and M81E) and seven nitrogen rates arranged in a RCBD with three replications. Sweet sorghum was harvested at soft dough stage and evaluated for total biomass yield, juice yield, forage quality at the time of harvest and quality of bagasse. Forage yields ranged from 60.5 to 94.9 tonne /ha and 75.5 to 98.2 tonne /ha in 2008 and 2009, respectively. Juice yields ranged from 7481 to 12626 litres /ha and 8587 to 13368 litres/ha in 2008 and 2009, respectively. There were no significant quality differences among nitrogen rates. The bagasse has 69, 3.9, 39.2, 66.3, 58.4 and 69, 4.7, 37.5 62.2, 59.6 % moisture, % Crude protein, ADF, NDF and TDN in M81E and Topper respectively. There was a positive response to fertilizer rates in 2008 and no significant difference in 2009.

Key Words

NUE, forage quality, biofuel, ethanol, nitrogen use efficiency.

Introduction

Energy demand in the world is increasing ever year due to increased consumption. Currently, US imports more than 60 % of its oil needs, so alternative renewable energy sources are warranted. Demand for ethanol is increasing drastically due to its direct use as well as blending in automotive fuels, which is desirable for getting clean exhaust and also to significantly reduce United States' dependence on foreign oil. U.S. produced around 6.5 giga litres of ethanol in 2007, mostly from corn. In U.S. currently, sweet sorghum (*Sorghum bicolor* L.), is produced mainly for cooking and as a livestock feed after its introduction from Africa. It has a high water use efficiency, rapid growth rate, early maturity and high total value. Sweet sorghum can be grown throughout temperate climate zones of the United States, including Oklahoma. Sweet sorghum is a drought-tolerant feed stock with the potential to produce more ethanol per acre than corn. Steduto *et al.* (1997) reported that water use efficiency of sweet sorghum at canopy level is higher than maize and grain sorghum. The crop only needs 30-38 cm of rain during the growing season to make a crop. Therefore, it is suitable for dry land production or limited irrigation. If the crop receives more moisture, it will respond positively to water. Freeman *et al.* (1973) has reported that sweet sorghum has given yield responses to N applications of 45 to 112 kg N/ha.

The idea of using sweet sorghum for commercial ethanol production is not new. Currently about 10 million tons of grain from the tops of the plant's stalks are harvested in the U.S., the world's leading grower, but most of the sugar from the stalks goes to make syrup for human and animal consumption. Sweet sorghum stalks contain up to 75% juice, varying between 12 and 23% in sugar. Antonopoulou *et al.* (2008) reported that sweet sorghum contains 43.6 – 58.2% soluble sucrose, glucose and fructose in the stalk and 22.6 – 47.8% insoluble cellulose and hemicelluloses. There's enough juice in a hectare of sweet sorghum to make 3700 to 7400 litres of ethanol. Sorghum juice-derived ethanol is cheaper to produce than corn ethanol because it doesn't require the cooking and enzymes that corn requires for conversion of starch to sugar to fuel grade alcohol. Current estimates suggest that intensive plant breeding and cultivation research could, over time, increase the sugar content of sorghum juice to a level needed to produce 9348 litres of ethanol per hectare. The taller the plant and the thicker the stalk, the more juice the plant will produce. The crop is long-rooted and can extract residual nitrogen left by previous crops, or from nitrogen-fixing soybeans preceding in crop rotation. The reason sweet sorghum is not as popular as corn in terms of being a source of ethanol in the United States has been the need to ferment its simple sugars immediately and the high costs associated with a

centralized processing plant that can be operated only seasonally. Some of the crop residue left after juice extraction (bagasse) can be dried and burned to fuel ethanol distillation. These residues can also be used for animal feed, paper, or fuel pellets. Ensiled bagasse has potential feed value for beef cattle. Depending on cellulosic biofuel refinery feasibility, bagasse can be baled and marketed to them. Vinsasse, the liquid left over after distillation could be used as a fertilizer source. The crop needn't be grown on a farmer's best land, allowing the farmer to make use of poorer ground. The simplicity of ethanol production from sweet sorghum could lend itself to on-farm or small-cooperative efforts at fuel-making.

In Oklahoma, the potential processing scenario might look like this: Plant sweet sorghum around mid-April, and then stagger plantings for two to three months. This would provide a harvest window of August through November. Limited research has been reported regarding the amount of nitrogen fertilizer required to optimize the juice production. The yields vary with the hybrid that is used for production and also there is limited research done on how varying levels of nitrogen interact with the juice yield quality and quantity of different hybrids. In order to address these questions of ethanol productivity and utilization of bagasse as a fodder from sweet sorghum, Noble Foundation in collaboration with the Oklahoma State University established a sweet sorghum variety by nitrogen fertility trial. The objective of this research is to evaluate sweet sorghum cultivars to determine the yield and quality of sweet sorghum's forage under different nitrogen rates as well as improve pressing and fermentation methods for possible ethanol production.

Materials and Methods

This experiment was initiated at Dupy farm, Gene Autry, Oklahoma in 2008 on dale silt loam (Fine-silty, mixed, superactive, thermic Pachic Haplustolls). Soil samples from 0 to 15 and 15 to 30 cm depths. The treatments are seven different N rates (0-0, 0-56, 56-56, 56-112, 112-0, 112-56, 168-0 preplant - topdress rates in kg/ha with two cultivars (Topper and M81E). The topdress applications are done at 10 leaf stage. The experimental design is a randomized complete block design with three replications. The experimental unit size is 1.53 m X 6.1 m. Seed was drilled in 76.2 cm rows with a Hege 500 research plot drill. Weeds were controlled mechanically by rotary hoe and chemically with 2, 4-D in 2008. In 2009, seed treated with Concept III safener and Cruiser insecticide. Cinch ATZ was used as pre-emergence herbicide. Forage was harvested at soft dough stage by cutting the center two rows using a blade attached weed eater to measure total biomass, juice content, sugar quality, bagasse yield and quality. Fresh biomass weight was measured on farm using a scale attached to back of a pickup truck. Stalks were pressed to extract juice using a roller presser built at Oklahoma State University. Fresh biomass and bagasse subsamples of the harvested biomass were collected for dry matter determinations and forage nutrient analysis. Following drying at 60°C, samples were ground to pass a < 1 mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) and prepared for nutrient analysis. Nutrient concentrations were estimated with near infrared spectroscopy (NIRS) analysis (Shenk and Westerhaus 1994) using equations developed by the NIRS Forage and Feed Testing Consortium and included dry matter, N, P, K, NDF, ADF, and in vitro dry matter digestibility (IVDMD), a laboratory bioassay that estimates the proportion of dry matter in forage digestible by a ruminant (Ball *et al.* 2001). Analysis of variance was conducted using the mixed models procedure in SAS to determine main effects and interactions of nitrogen fertilizer rate and application time. Nitrogen rate and application time were considered fixed effects and replication random. Polynomial contrasts were computed to determine the quantitative relationship of N rate to biomass yield and nutrient concentration.

Results

Forage yields

Forage yields ranged from 60.5 to 94.9 tonne /ha and 75.5 to 98.2 tonne /ha in 2008 and 2009, respectively (Figure 1). There was a positive response to N in 2008, with increase in N the forage biomass production also increased in both cultivars M81E and Topper. Total forage biomass was not significantly affected by different N rates in 2009 in Topper. For M81E at lower N rates the total yields in 2008 were lower than yields in 2009 due to persisting weed competition from both pigweed and crabgrass and at higher N rates there was no significant difference among both years. In Topper year has significant effect only in the control plot and at any N fertility level year didn't had a significant effect. In 2009 there was no significant difference in biomass yields which may be due 56 kg N/ha of residual soil N.

Juice yields

Juice yields ranged from 7481 to 12626 litres /ha and 8587 to 13368 litres/ha in 2008 and 2009, respectively (Figure 2). There was a positive response to N in 2008, with increase in N the juice yields also increased in

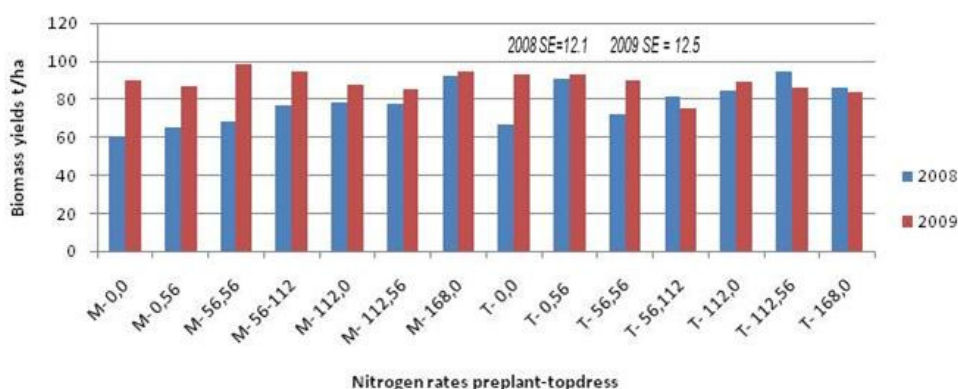


Figure 1. Forage biomass yields (fresh weight) in tonnes per hectare of M81-E (M) and Topper (T) under different rates and times of application of Nitrogen fertilizer at Dupy farm, Ardmore, OK.

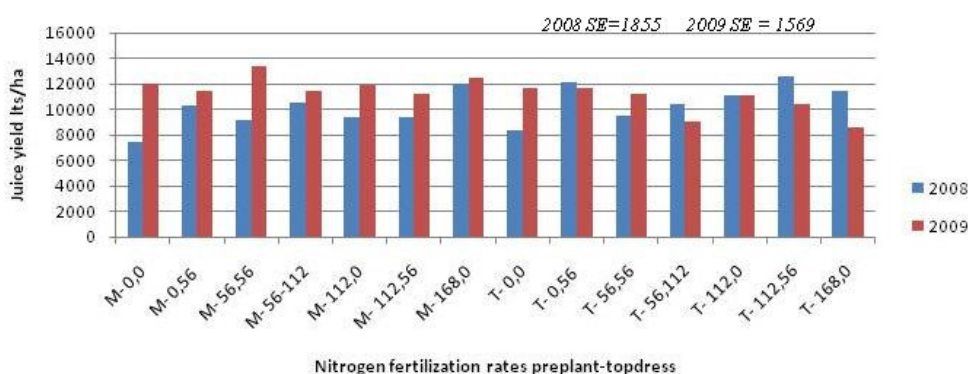


Figure 2. Juice yields in litres per hectare of M81-E (M) and Topper (T) under different rates and times of application of Nitrogen fertilizer at Dupy farm, Ardmore, OK.

both cultivars M81E and Topper. Juice yields were not significantly affected by different N rates in 2009 in Topper. For M81E at lower N rates the juice yields in 2008 were lower than yields in 2009 due to persisting weed competition from both pigweed and crabgrass and at higher N rates there was no significant difference among both years. In Topper year has significant effect only in the control plot and at any N fertility level year didn't had a significant effect. In 2009 there was no significant difference in juice yields which may be due 56 kg N/ha of residual soil N.

Moisture content and quality of forage and bagasse

The moisture content of forage ranged from 72 to 73% in both the varieties (Figure 4). The bagasse has 69, 3.9, 39.2, 66.3, 58.4 and 69, 4.7, 37.5 62.2, 59.6 % moisture, % Crude protein, ADF, NDF and TDN in M81E and Topper respectively. The higher moisture content in the bagasse indicates that there is room to improve press operation/pressure. The quality parameters of both the cultivars indicate that bagasse can be ensiled and used as feed for cattle

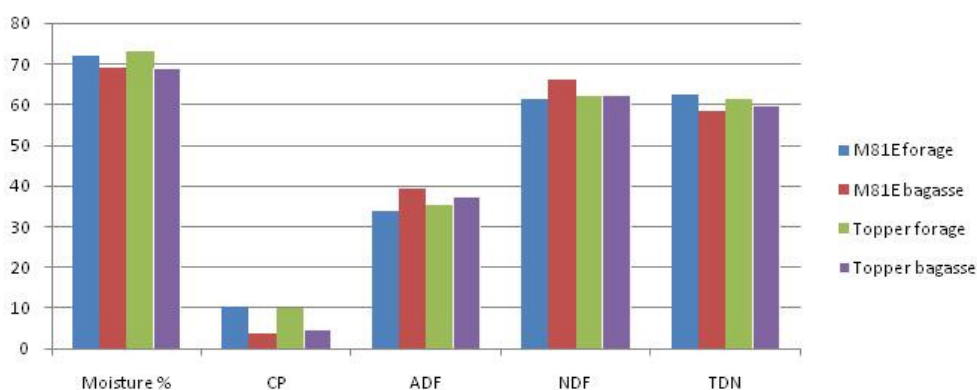


Figure 3. Forage and bagasse Moisture content and forage quality of M81-E and Topper at Dupy farm, Ardmore, OK.

Conclusions

This study evaluated the effects of nitrogen fertilization rates and timing on biomass yield and juice yields of two sweet sorghum cultivars M81E and Topper. Two years of study indicated that if there is enough residual nitrogen present in the soil the nitrogen fertilizer rates will not have a significant effect on forage yield as well as juice produced. If there is heavy weed pressure from pigweed and crabgrass M81E will tend to produce lower yields compared to Topper as evidenced in 2008 and under low weed pressure both the varieties produced almost the same amount of forage biomass and juice yields as evidenced in 2009 results. The bagasse left over after on farm extraction of juice has enough good quality that it can be ensiled and used as a feed for cattle. There is still some room to improve on farm extraction as evidenced by higher moisture content in bagasse that was left over after extraction of juice.

References

- Antonopoulou G, Gavala HN, Skiadas IV, Angelopoulos K, Lyberatos G (2008) Biofuels generation from sweet sorghum: fermentative hydrogen production and anaerobic digestion of the remaining biomass. *Bioresources Technology* **99**, 110–119.
- Ball, DM, Collins M, Lacefield GD, Martin NP, Mertens DA, Olson KE, Putnam DH, Undersander DJ, Wolf MW (2001) 'Understanding Forage Quality'. American Farm Bureau Federation Publication 1-01. (Park Ridge: Illinois).
- Freeman, KC, Broadhead DM. and Zummo N (1973) 'Culture of Sweet Sorghum for Syrup Production' USDA Agriculture Handbook. 441. (U.S. Government Printing Office: Washington, DC)
- Shenk JS, Westerhaus MO (1994) The application of near infrared reflectance spectroscopy (NIRS) to forage analysis. In 'Forage Quality, Evaluation, and Utilization'. (Ed GC Fahey) pp. 406-449. (ASA-CSSA-SSSA: Madison, Wisconsin).
- Steduto P, Katerji N, Puertos-Molina H (1997) Water-use efficiency of sweet sorghum under water stress conditions: gas-exchange investigations at leaf and canopy scales. *Field Crop Res.* **54**, 221–234.

Effect of organic ligands on phosphate adsorption and availability in Andisols of eastern Hokkaido, Japan

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Abstract

Andisols usually fix large amounts of phosphate on surface-reactive sites. Competitive effects of natural organic ligands, like citric acid and water-soluble organic matter (WSOM), on phosphate adsorption and availability to plants in Andisols were studied. Three types of Andisols were selected and soil samples were collected from surface horizons of upland fields. Phosphate adsorption isotherms were measured to evaluate effects of organic ligands on phosphate adsorption. Pot experiments were also conducted to investigate effects of the combined application of fertilizer and manure on phosphate availability. A suppressive effect of concurrent addition of citrate on phosphate adsorption was observed for all Andisols. Previous addition of citrate was more effective to suppress the phosphate adsorption in humic Andisols. Effects of the WSOM from cattle manure on phosphate adsorption could be observed clearly at the low concentration of phosphate. The most significant effect of WSOM on phosphate adsorption in the Andisols was to severely reduce the binding strength of phosphate and possibly induce subsequent phosphate desorption. The combined application of manure and inorganic phosphate fertilizer could improve the availability and efficiency of phosphate, by reducing phosphate adsorption and increasing phosphate solubility in the Andisols.

Key Words

Andisols, organic ligand, phosphate adsorption, phosphate availability, citrate, manure.

Introduction

Phosphates are a limited non-renewable resource, which cannot be replaced by other substances, as an essential plant nutrient (Franz 2008). Phosphates are mostly obtained from mined rock phosphate and its existing reserves could be exhausted in the next 50-100 years. Efficient use and alternative management of phosphate fertilizers are critical to ensure global food production and security (Cordell *et al.* 2009). Most of the arable land of eastern Hokkaido, which is one of the largest agricultural areas in Japan, is widely covered with volcanic ash and the soils are often classified as Andisols. The availability of phosphate fertilizer for plant uptake is extremely low in Andisols due to increased phosphate sorption and retention onto Al-humus complexes and amorphous to para-crystalline clay minerals, such as allophane and imogolite (Wada 1989). Andisols usually fix large amounts of phosphate by ligand exchange reaction with Al-OH and Al-H₂O functional groups on these constituents. There is considerable evidence that naturally-derived organic matter may influence soil chemical and biological processes, and enhance phosphate availability (Scheffe *et al.* 2009). Natural organic ligands in soils, which consist of a mixture of well-defined organic acids and organic compounds that do not have a defined chemical structure like humic and fulvic acids can block some surface-reactive sites on minerals and hydroxides, thereby reducing the phosphate adsorption and increasing phosphate availability (Antelo *et al.* 2007). Although the competitive adsorption of phosphate and organic ligands by synthetic and natural clay minerals, iron oxides, and highly weathered acidic soils, such as Oxisols and Ultisols, have been studied (Hu *et al.* 2001; Antelo *et al.* 2007; Scheffe *et al.* 2009), there is limited information on the fate of phosphate in the presence of organic ligands in Andisols. The aims of this study are to identify the effects of organic acid (citrate) and water-soluble organic matter extracted from aerobically composted cattle manure on phosphate adsorption and availability to plants in Andisols and to increase the efficiency of phosphate and contribute to the sustainable food production.

Materials and Methods

Soil samples and their characterization

Soil samples were collected from three upland fields in and around Obihiro, Hokkaido, Japan. The soils are classified into three subgroups of Andosols in the Japanese cultivated soil classification, which are Haplic Wet Andosols (Typic Melanaquands), Cumulic Andosols (Typic Melanudands), and Low-humic Andosols

Table 1. Several physico-chemical and mineralogical properties of the soil samples.

Soil subgroups	pH(H ₂ O) ^a	PAC ^b	Total C ^c	Al _p ^d	Al _o ^e	Si _o ^e	Allophane ^f	CEC ^g	AEC ^g
					(g/kg)				(cmol _c /kg)
Haplic Wet Andosols	5.4	1670	87.5	9.50	19.4	5.71	40.3	36.4	0.35
Cumulic Andosols	5.3	1650	53.2	7.36	28.1	13.0	87.1	34.5	1.33
Low-humic Andosols	5.7	1650	29.6	5.12	37.9	17.9	131	26.9	2.42

^aSoil/water ratio of 1:2.5. ^bPhosphate absorption coefficient obtained by a Japanese conventional method. ^cTotal carbon determined by the dry-combustion method. ^dAluminium extracted with sodium pyrophosphate. ^eAluminum and silicon extracted with acid ammonium oxalate, respectively. ^fEstimated from Al_p, Al_o and Si_o. ^gCation and anion exchange capacity at pH5.5 determined by a centrifugation method, respectively.

(Typic Hapludands). Although the fields were located on the same volcanic ash terrace, slight differences in the micro topography and subsequent moisture conditions in the subsoils affected their formation processes and soil physico-chemical properties (Table 1). The surface soil samples at the depth of 0-20 cm were collected from each field, air-dried, and passed through a 2 mm pore-size sieve.

Adsorption isotherms of phosphate in the presence of citric acid

Phosphate adsorption isotherms were measured to evaluate the effects of citric acid on phosphate adsorption. One gram of the air-dried soil sample was placed in a 50-mL plastic centrifuge tube. 15 mL of 0.2 mol/L KNO₃ at pH5.5 was added to each tube. After shaking for 1 h at 25 °C, the pH of the suspension was readjusted to 5.5. 0-5 mL of 0.1 mol/L KH₂PO₄ and 5 mL of 0.05 mol/L citric acid were added to each tube. Soil/solution ratio was adjusted to 1:25. Initial concentration of phosphate and citrate was 0 to 20 mmol/L and 10 mmol/L, respectively. The tubes were shaken for 24 h at 25 °C, centrifuged at 10,000 G for 10 min, filtered through a 0.45-μm membrane filter, and the P concentration in the supernatant was determined by ICP-AES. The experiments were conducted in duplicate. The linear form of the Langmuir adsorption equation was used to describe phosphate adsorption maxima (*b*) and binding strength (*k*) on the Andisols. The effects of additional sequences of citric acid and phosphate on phosphate adsorption were also examined. Experiments were conducted as follows: (1) addition of citrate after phosphate adsorption for 24 h at 25 °C; (2) addition of phosphate after citrate adsorption for 24 h at 25 °C. Other procedures for shaking and determination of P in the supernatant were also the same as mentioned above.

Adsorption isotherms of phosphate in the presence of water-soluble organic matter from cattle manure

The effects of water-soluble organic matter (WSOM) extracted from aerobically composted cattle manure on phosphate adsorption were examined. The well-composted manure sample was oven-dried and ground finely. One gram of the air-dried soil sample and 0.1 g of the oven-dried manure sample were placed in a 50-mL plastic centrifuge tube. 20 mL of 0.15 mol/L KNO₃ at pH5.5 was added to each tube. After shaking for 1 h at 25 °C, the pH of the suspension was readjusted to 5.5. 0-5 mL of 0.1 mol/L KH₂PO₄ was added to each tube. 0-5 mL of 0.02 mol/L KH₂PO₄ was also added to each tube to examine the effects of WSOM on phosphate adsorption at lower phosphate concentration (0 to 4 mmol/L). Other procedures for shaking and determination of P in the supernatant were also the same as mentioned above. The experiments were conducted in duplicate.

Pot experiments of the combined application of manure and inorganic phosphate fertilizer

The pot experiment was conducted to investigate the effects of mixing cattle manure with a phosphate fertilizer on the availability of phosphate for plant uptake. Soil sample was collected from an upland field at Obihiro University of Agriculture and Veterinary Medicine, air-dried and passed through 2-mm sieve. The soil is classified as Low-humic Andosols (Typic Hapludands). The soils were amended with 100 mg N/pot from (NH₄)₂SO₄, 100 mg K₂O/pot from K₂SO₄, and superphosphate at the rate of 0, 50, 100, and 150 mg P₂O₅/pot (F0, F50, F100, and F150, respectively). The soils were also amended with the same amounts of (NH₄)₂SO₄ and K₂SO₄, and the mixture of superphosphate with 5 g of dried and ground cattle manure at the rate of 0, 50, and 100 mg P₂O₅/pot (F0+M, F50+M, and F100+M, respectively). The experiments were conducted in triplicate. The manure contained 9.6 g N/kg, 10.5 g P₂O₅/kg, and 4.7 g K₂O/kg. The amended soil was then moistened to 50 % of water-holding capacity and distributed into the Neubauer's pots (600 mL, 0.01 m²). Each pot was planted with nine spinach seeds and placed in a growth chamber (day/night temperature, 25/15 °C; photoperiod, 16-h light and 8-h dark; relative humidity of 70 %). After germination, the plants were thinned to three per pot. The spinach shoot and root were harvested after 20 days of growth. The plants were oven-dried at 60 °C to determine dry matter yields of spinach. The dried plant samples were then ground and analysed for plant tissue P concentration by the Kjeldahl digestion method and ICP-AES.

Results and Discussion

Effects of citric acid on phosphate adsorption in Andisols

Phosphate adsorption isotherms without citrate for each soil were relatively similar and indicated that the Andisols could fix large amounts of phosphate (Figure 1). The values of adsorption maxima (b) calculated from the Langmuir equation were 13.6, 14.7, and 13.9 g P₂O₅/kg for Haplic Wet Andosols (WA), Cumulic Andosols (CA), and Low-humic Andosols (LA), respectively. The suppressive effect of concurrent addition of citrate on phosphate adsorption was observed for all Andisols. At the highest concentration, the reduction of phosphate adsorption reached 20–40 %, and the order of reduction was WA > CA > LA. The effect of the order of addition of citrate and phosphate to the Andisols was also clearly observed. The previous addition of citrate (phosphate after citrate) was more effective to suppress the phosphate adsorption in the WA and CA, where more than 50 % of the phosphate adsorption was reduced. On the other hand, the previous addition of phosphate (phosphate before citrate) was not effective to reduce the phosphate adsorption in the Andisols. When phosphate was added first, phosphate could be adsorbed on the surface-reactive site of the Andisols more easily. In this case, the subsequent addition of citrate only results in desorption of the phosphate which was adsorbed weakly to the surface (Hu *et al.* 2001). The suppressive effect of citrate on the phosphate adsorption was higher in the WA, of which reactive sites for phosphate adsorption dominated by Al-humus complexes (Table 1). The previous addition of citrate could induce citrate adsorption and desorption of humic substances from the solid phase through ligand exchange reaction and/or Al-citrate complexation, resulting in competitive adsorption of phosphate with water-soluble humic substances.

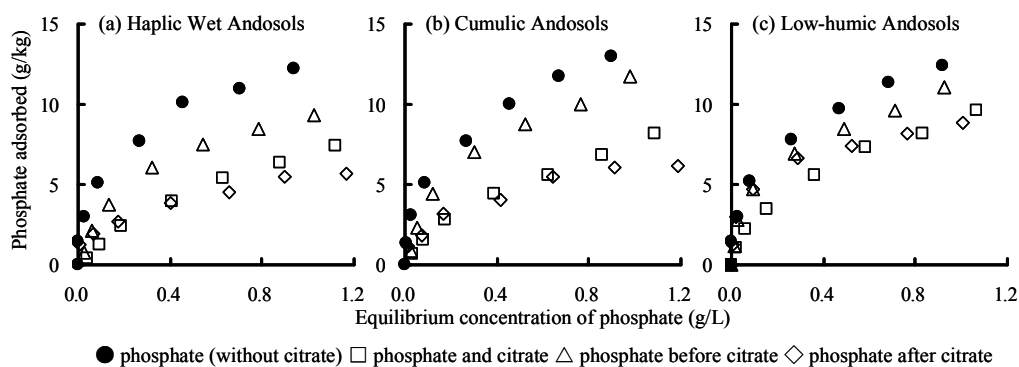


Figure 1. Phosphate adsorption isotherms of the Andisols in the absence and presence of citrate (a) Haplic Wet Andosols, (b) Cumulic Andosols, and (c) Low-humic Andosols.

Effects of water-soluble organic matter from cattle manure on phosphate adsorption in Andisols

The effects of the presence of cattle manure on phosphate adsorption at the high concentration of phosphate were not obvious compared with those of citrate (Figure 2a). However, the effects could be observed clearly at the low concentration of phosphate for all Andisols, especially for the LA (Figure 2b).

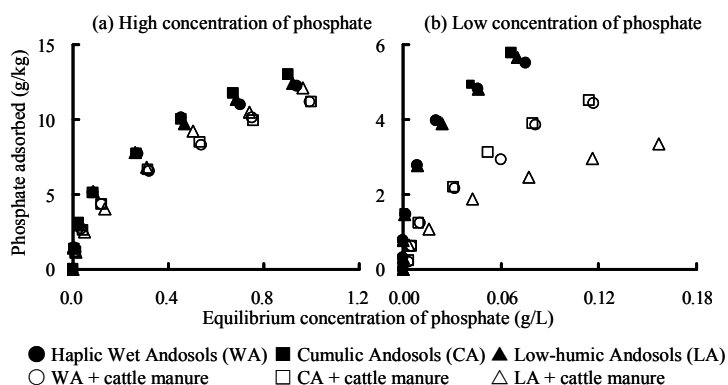


Figure 2. Phosphate adsorption isotherms of the Andisols in the absence and presence of cattle manure (a) at high concentration of phosphate (0–20 mmol/L) and (b) at low concentration of phosphate (0–4 mmol/L).

It had been confirmed that the adsorption of phosphate on the manure and desorption of phosphate from manure had only a slight influence on the phosphate adsorption isotherms from the preliminary experiments (data are not shown). The aerobically composted manure used in this study released a high concentration of

water-soluble organic matter (WSOM), of which water-soluble organic carbon content was 15.2 mg C/g and dominated with humic acid (47 %) and fulvic acid (25 %). Strong competition of organic ligands, humic and fulvic acids with phosphate for adsorption sites has been identified as one mechanism by which humic substances inhibit phosphate adsorption by soil colloids (Agbenin and Igbokwe 2006). The values of the binding strength (k) calculated from the Langmuir equation were 0.16, 0.19, and 0.18 in the absence of the manure, and reduced to 0.019, 0.021, and 0.018 in the presence of manure for the WA, CA, and LA, respectively. The most significant effect of WSOM from the cattle manure on phosphate adsorption in the Andisols at the low P concentration was to severely reduce the binding strength (k) of phosphate and possibly induce subsequent phosphate desorption and solubility.

Availability of phosphate in the presence of mixture of cattle manure and phosphate fertilizer

Dry matter yields of spinach and amounts of phosphate absorbed by the plants increased significantly with increase in the amounts of phosphate applied to the pots from an inorganic fertilizer (Table 2). Since sufficient amounts of inorganic nitrogen and potassium were applied to the pots, these results apparently indicate that the phosphate availability was one of the most critical limiting factors for plant growth in the Andisols. When the phosphate fertilizer was mixed with cattle manure, the dry matter yields of spinach shoot increased significantly. At the same level of applied phosphate from the fertilizer and manure, for example, comparing F150 and F100+M, the dry matter yields were not different significantly; however, the amounts of phosphate absorbed by the shoot and whole plants were significantly different. These results indicated that the combined application of manure and inorganic phosphate fertilizer could improve the availability and efficiency of phosphate, by reducing phosphate adsorption and increasing phosphate solubility in the soils.

Table 2. Dry matter yield of spinach and amount of phosphate absorbed by spinach in the pot experiment.

Plot	Phosphate applied (mg P ₂ O ₅ /pot)			Dry matter yield (mg/pot)			Phosphate absorbed (mg P ₂ O ₅ /pot)		
	Fertilizer	Manure	Total	Shoot	Root	Whole	Shoot	Root	Whole
F0	0	0	0	0.10 a	0.05 a	0.15 a	0.25 a	0.12 a	0.37 a
F50	50	0	50	0.22 ab	0.16 b	0.38 ab	0.77 ab	0.83 b	1.60 ab
F100	100	0	100	0.38 bc	0.29 c	0.66 cd	1.96 c	1.68 c	3.63 c
F150	150	0	150	0.65 cd	0.41 d	1.06 e	4.27 d	2.57 d	6.83 e
F0+M	0	52	52	0.34 b	0.14 b	0.48 bc	1.72 bc	0.78 b	2.49 bc
F50+M	50	52	102	0.53 c	0.21 bc	0.74 d	3.68 d	1.45 c	5.12 d
F100+M	100	52	152	0.81 d	0.27 c	1.08 e	5.92 e	2.40 d	8.33 f

Means followed by the same letter within each column are not significantly different at $P < 0.05$ by Tukey's test.

Conclusion

Natural organic ligands, such as organic acids and water-soluble humic substances in the organic amendments, could be interposed between phosphate and reactive sites in Andisols, protecting phosphate from direct interaction or bonding with soil surface-reactive sites, and reducing phosphate adsorption. Phosphate availability and efficiency could be improved by combination of inorganic phosphate fertilizer and manure, probably due to the effects of organic-ligands to reduce phosphate adsorption and increase phosphate desorption in Andisols.

References

- Agbenin JO, Igbokwe SO (2006) Effect of soil-dung manure incubation on the solubility and retention of applied phosphate by a weathered tropical semi-arid soil. *Geoderma* **133**, 191-203.
- Antelo J, Arce F, Avena M, Fiol S, López R, Macías F (2007) Adsorption of a soil humic acid at the surface of goethite and its competitive interaction with phosphate. *Geoderma* **138**, 12-19.
- Cordell D, Drangert J-O, White S (2009) The story of phosphorus: Global food security and food for thought. *Global Environmental Change* **19**, 292-305.
- Franz M (2008) Phosphate fertilizer from swage sludge ash (SSA). *Waste Management* **28**, 1809-1818.
- Hu HQ, He JZ, Li XY, Liu F (2001) Effect of several organic acids on phosphate adsorption by variable charge soils of central China. *Environmental International* **26**, 353-358.
- Schefe CR, Kappen P, Zuin L, Pigram PJ, Christensen C (2009) Addition of carboxylic acids modifies phosphate sorption on soil and boehmite surfaces: A solution chemistry and XANES spectroscopy study. *Journal of Colloid and Interface Science* **330**, 51-59.
- Wada K (1989) Allophane and Imogolite. In 'Minerals in Soil Environments 2nd Edition'. (Eds JB Dixon, SB Weed) pp. 1051-1087. (SSSA: Madison).

Effect of P and Si amendment on the charge characteristics and management of a Geric soil

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Abstract

Improving surface charge characteristics of geric Ferralsols may increase nutrient retention in highly weathered tropical soils of Vietnam. Application of increasing amounts of fused magnesium phosphate (FMP) increased soil pH by one unit and cation exchange capacity (CEC) 10-fold following 7 days incubation near field capacity at 40°C. Similarly, calcium and magnesium silicate amendments at rates designed to apply the same amount of silicon as a high FMP application also increased pH and CEC. In contrast pH₀ remained relatively unchanged except following high silicon application. It is recommended that strategies that increase pH are more likely to increase CEC in geric soils than amendments that aim to lower the pH₀.

Key Words

Soil charge, geric property, pH₀, CEC, silicate, fused magnesium phosphate, phosphorus buffer index, charge fingerprint.

Introduction

In Vietnam, upland soils such as Acrisols and Ferralsols cover about 72 percent of the total surface (Nguyen and Thai 1999; Ton *et al.* 1996). These highly weathered tropical soils are characterised by high desilication, soil acidity and phosphorus fixation and are intensively cultivated with minimal fertiliser input (Nguyen and Thai (1999). Soil surface charge is often characterized by net positive charge, a geric property, especially in the subsoil layer of Ferralsols (Moody and Phan 2008), where the soil pH in water is close to or lower than that in 1 M KCl (Phan *et al.* 2005). Therefore, cations are easily leached and soil fertility conditions deteriorate. Theoretically, cation loss can be prevented by developing negative surface charge and thus creating additional cation exchange capacity (CEC) (Uehara and Gillman 1981). This can be obtained either by raising soil pH, increasing the electrolyte concentration in the soil solution or lowering the pH₀. Soil amendments that may affect these soil properties include lime, phosphate, silicate and organic matter application. This paper presents the effect of P and Si amendment application on the charge characteristics of a Ferralsol from north Queensland having similar charge characteristics to Ferralsols in the uplands of Vietnam.

Materials and methods

Soil collection

Soil was collected at a depth of 20-40cm (to remove interference from organic matter in determining charge characteristics) from a Pingin series Red Ferrosol under sugarcane cultivation in north Queensland. This soil has similar geric properties to many upland soils in Vietnam. The sample was air-dried and passed through a 2mm-sieve before taking a representative sample for incubation and analysis. Soil properties and soil charge characteristics are presented in Table 1.

Soil incubation and analysis

A 100 g soil sample with 20% moisture content, *i.e.* 100 g soil + 20 mL water, was incubated in a pot placed in the oven at 40°C. Water was added daily to replace evaporative losses and to maintain moisture content at 20%. Eight treatments were involved in this study. Fused magnesium phosphate (FMP) was applied at the rates of 0, 75, 150 and 300 mg P /kg. The silicate materials, wollastonite (Ca-Si) and olivine (Mg-Si) were added at rates equal to the Si content in FMP at 300 mg P /kg *i.e.* 320 mg Si /kg. Similarly, two other silicate materials, acidulated wollastonite (Ac-Ca-Si) and acidulated olivine (Ac-Mg-Si), were added to be equivalent in applied Si to that of the 150 mg P /kg application of FMP, *i.e.* 160 mg Si /kg. Chemical components of amendments are presented in Table 2.

Table 1. Soil and soil charge properties of a Pingin subsoil (20-40cm).

Si (%)	Si salt ext. ^A (μM)	P sorbed ^B (mg/kg)	Soil pH ^C	pH ₀	CEC _b ^D	CEC _t ^E	AEC ^F	PZNC ^G
					(cmol _c /kg)			
6.48	78	985	4.27	4.67	0.22	0.24	0.62	4.79

^A0.01M CaCl₂ (1:1000 ratio of soil:solution); ^BP sorbed from added 1000 mg P /kg; ^CSoil pH in 0.002 M CaCl₂ (1:10 ratio of soil:solution); ^DCEC_b – Base cation exchange capacity; ^ECEC_t – Total cation exchange capacity; ^FAEC – Anion exchange capacity; ^GPZNC – Point of zero net charge.

Table 2. Chemical components of amendments.

Amendments	P (%)	Si (%)	Si salt extractable _A (μM)	Neutralising value (%)
FMP	7.11	7.47	139	47.7
Ca-Si	-	25.65	167	48.1
Ac-Ca-Si	-	20.00	nd	0
Mg-Si	-	11.02	103	53.3
Ac-Ca-Si	-	7.23	525	0

^A0.01M CaCl₂ (1:1000 ratio of soil:solution).

After seven days of incubation, soils were analysed for pH, pH₀, basic cation exchange capacity (CEC_b), total cation exchange capacity (CEC_t), anion exchange capacity (AEC) and point of zero net charge (PZNC) by using the charge fingerprint procedure (Gillman 2007); Colwell extractable P (Colwell 1963) and phosphorus buffering index (PBI) (Burkitt *et al.* 2002) were also determined.

Results

After seven days of incubation at high temperature (40°C), soil pH (in 0.002 M CaCl₂, 1:10) increased with increasing levels of applied FMP, about one unit pH increment after treatment with 300 mg P /kg (Figure 1). FMP applications also shifted pH₀ and PZNC to lower values than that of the incubated control; the more P applied, the lower the values of pH₀ and PZNC. In comparison with the non-incubated baseline soil (Table 1), soil pH and pH₀ were higher in all incubated treatments, while PZNC was lower (Figure 1).

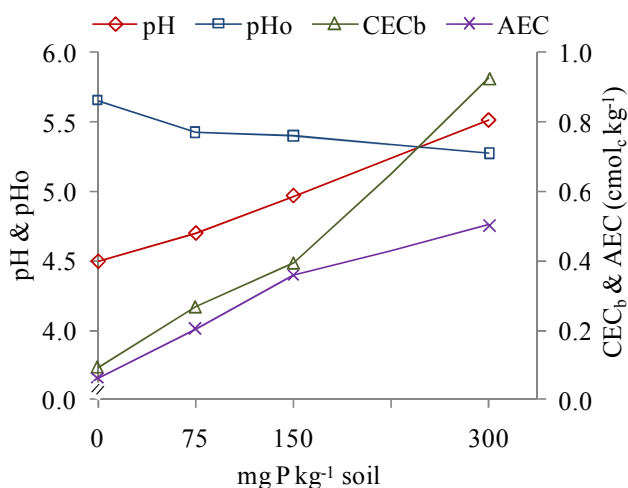


Figure 1. Change in soil pH and charge characteristics of a Pingin series subsoil as a function of P application as fused magnesium phosphate following incubation for 7 days at 40°C near field capacity.

Phosphorus affected both CEC and AEC of the soil, the higher P application, the greater the increase in CEC and AEC (Figure 1). However, the increase in AEC was smaller than CEC following application of 300 mg P /kg. Phosphorus availability measured by Colwell (1963) extraction increased linearly from 34 to 100 mg/kg with increasing P application as FMP. A corresponding decrease in PBI from 840 to 700 was also observed. Where Pingin soil was treated with unacidulated silicate amendments, soil pH increased and pH₀ decreased (Table 3). In contrast, PZNC was higher in silicate treated soils compared to the incubated control, except the soil with Ac-Mg-Si. CEC and AEC also increased with silicate applications, but AEC decreased in the Ac-Ca-Si treatment. Similar to the effects with P application, silicate addition resulted in higher pH₀ and lower PZNC than those of the non-incubated baseline soil, but CEC and AEC of the soil treated with silicates were reduced in comparison to the non-incubated initial values. The exception was the Ac-Mg-Si treatment where both CEC_b and CEC_t were kept at the same values as the non-incubated baseline soil (Table 1 and 3).

Table 3. Effect of Si application on the charge characteristics, P availability and PBI of a Pingin series subsoil incubated for 7 days at 40°C near field capacity.

Amendments	Si added (kg /ha)	pH _(CaCl2) (1:10)	pH ₀	PZNC	CEC _b	CEC _t	AEC	Colwell P	PBI
					(cmol _c /kg)				
Control	0	4.49	5.63	4.28	0.09	0.11	0.06	33.5	838
Ca-Si	420	4.88	5.41	4.43	0.19	0.21	0.10	35.8	798
Ac-Ca-Si	210	4.54	5.41	4.35	0.11	0.14	0.01	33.1	812
Mg-Si	420	4.81	5.43	4.42	0.17	0.18	0.11	33.6	816
Ac-Mg-Si	210	4.61	5.32	4.14	0.21	0.23	0.11	31.5	784

Although Colwell P was not responsive to applied silicates, PBI decreased (Table 3). Hence soil P sorption capacity may be reduced by applying silicate.

Discussion

The application of FMP and raw silicate materials (Ca-Si and Mg-Si) increased soil pH accounting for the majority of change in soil CEC_b (Figure 1, Table 3). Increased soil pH following application of phosphate or silicate ions to ferric soils is most likely associated with release of hydroxide ions following specific adsorption reactions (Smyth and Sanchez 1980). Hence the most effective way to increase charge in geric soils is to increase soil pH rather than adjust pH₀.

The exception to this trend occurred following application of acidulated Mg-Si where minimal change in pH was observed, yet CEC_b more than doubled (Table 3). The majority of the change in CEC_b for this amendment may be associated with lowering of the pH₀. The pH₀ of treated soils shifted to lower values compared to the incubated control; this can be attributed to the specifically adsorbed anions HPO₄²⁻ and SiO₄²⁻ that are released from FMP and silicate amendments (Qafoku *et al.* 2004; Uehara and Gillman 1981; Zhang and Zhao 1997). However, the pH₀ of all incubated soils, including the control, were higher than the pH₀ value of the non-incubated baseline soil. A number of factors may be involved with shift in pH₀ following incubation. First, the presence of Ca in the amended treatments may result in charge reversal due to Ca adsorption into the Stern layer (Uehara and Gillman 1981). Wann and Uehara (1978) observed similar results following Ca-Si amendments on Oxisols. Second, organic carbon coating Fe and Al oxides might have oxidised/mineralised during incubation at 40°C, thus exposing surfaces with a relatively higher pH₀. This explanation seems less likely because the test soil is a subsoil, but organic C analyses to compare incubated with non-incubated soils remain to be undertaken.

The interesting result of this study is that only the pH₀ value of FMP applied at 300 mg P /kg was lower than soil pH. This might be caused by the dual effects of P and Si anions that were released from FMP fertiliser. The relationship between soil pH and pH₀ determines the magnitude of net charge; therefore, on one hand the CEC in this treatment was greatly increased, and on the other hand PZNC was greatly decreased compared to the other treatments. In addition, FMP application brought about an increase in Colwell P and reduced PBI of the soil. This is a logical effect of the P content in FMP and also the competitive effect of Si content in FMP with P on the adsorptive sites.

Among silicate sources, although Ac-Mg-Si did not increase soil pH as much as Ca-Si and Mg-Si, it was the most responsive amendment in terms of reducing pH₀ and increasing CEC_b of the soil. Also, Ac-Mg-Si did not increase Colwell P, but it decreased PBI to the lowest value compared to the other silicate sources (Table 3). These effects can be explained by more available Si being released to the soil from this product than the others, as salt extractable Si of Ac-Mg-Si was much higher than that in the other silicate amendments (Table 2).

Conclusion

The Pingin series subsoil has similar charge characteristics to those of the geric Ferralsols of the uplands of Vietnam in terms of very low CEC and high pH₀. The application of FMP fertiliser not only overcomes a potential phosphorus deficiency, but through increasing pH may also increase soil charge and increase nutrient retention. Applying Ca-Si and Mg-Si materials can also rectify the problem of the geric property in highly weathered tropical soils by increasing the nutrient holding capacity of the soil and increasing P availability to the plant by the adsorptive competition of Si with P for sorption sites.

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References

- Burkitt LL, Moody PW, Gourley CJP, Hannah MC (2002) A simple phosphorus buffering index for Australian soils. *Australian Journal of Soil Research* **40**, 497-513.
- Colwell JD (1963) The estimation of phosphorus fertiliser requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 190-197.
- Gillman GP (2007) An analytical tool for understanding the properties and behaviour of variable charge soils. *Australian Journal of Soil Research* **45**, 83-90.
- Moody PW, Phan TC (2008) 'Soil Constraints and Management Package (SCAMP): Guidelines for Sustainable Management of Tropical Upland Soils'. (Australian Centre for International Agricultural Research: Canberra).
- Nguyen TS, Thai P (1999) 'Upland Soils in VIETNAM, Degradation and Rehabilitation'. Agricultural (Publishing House: Hanoi) (in Vietnamese)
- Phan TC, Cong DS, Nguyen QC, Nguyen BD (2005) 'Replenishing the Phosphorus Capital in Depleted Soils of the Central Highlands and the Eastern Region of South Vietnam'. Project ET-2000/PRV (VLIR) - 05, Hochiminh city (in Vietnamese)
- Qafoku NP, Ranst EV, Noble A, Baert G (2004) Variable charge soils: Their mineralogy, chemistry and management. *Advances in Agronomy* **84**, 159-215.
- Smyth TJ, Sanchez PA (1980) Effects of lime, silicate, and phosphorus applications to an Oxisol on phosphorus sorption and ion retention. *Soil Science Society of America Journal* **44**, 500-505.
- Ton TC, Tran KT, Nguyen TD, Nguyen TS, Le TB (1996) 'Soils in Vietnam'. (Agricultural Publishing House: Hanoi) (in Vietnamese)
- Uehara G, Gillman GP (1981) 'The Mineralogy, Chemistry, and Physics of Tropical Soils with Variable Charge Clays'. (Westview Press, Inc.: Boulder, Colorado).
- Wann SS, Uehara G (1978) Surface manipulation in constant surface potential soil colloids: I. Relation to sorbed phosphorus. *Soil Science Society of America Journal* **42**, 565-570.
- Zhang XN, Zhao AZ (1997) Surface Charge. In 'Chemistry of variable charge soils'. (Ed TR Yu) pp. 17-63. (Oxford University Press: New York).

Effect of sources of sulphur on yield and disease incidence in crops in Jiangxi Province, China

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Abstract

The Jiangxi Academy of Agricultural Sciences (JAAS) has conducted five experiments to compare elemental S and sulphate S containing fertilizers. The elemental S containing fertilizer used was a sulphur enhanced di-ammonium phosphate (SEF12) and the sulphate S was supplied from single superphosphate (SSP). A di-ammonium phosphate (DAP) control was used. In a cabbage experiment conducted in 2003 there was a significant response to S and a lower incidence of soft rot where SEF12 was applied (18-19% reduction compared to DAP, c.f. 5% with SSP) and leaf disease (20-31% reduction, c.f. 19% with SSP) where elemental S was applied. In two rice experiments there was a greater response to SEF12 compared to SSP and this was associated with a lower incidence of disease and insects (rice leaf roller and brown plant hopper) where SEF12 was applied. Incidences of rice leaf blight and rice blast were also observed on the DAP and SSP treatments. Two plot trials with rapeseed were established in 2006 in which the fertilizers were applied either at rates to deliver the same rate of P as applied in DAP at Maying Shishan or with the same rate of S as applied in SSP at Maying Sequ. At the Maying Shishan site there was a significant response to S in SSP and SEF12 when applied at the same P application rate. At the Maying Sequ site SEF12 out yielded SSP when applied at the same S rate. These trials are the first to report soil applied elemental S having an effect on protecting crops against insects and disease and indicate that the mechanism involved requires further investigation in both upland and flooded crops.

Key Words

Elemental S, sulphate, cabbage, rice, rapeseed.

Introduction

Sulphur is one of the essential elements required for the normal growth of plants and concentrations of S in plants are lower than that of N and similar to P. Sulphur plays an important role as a constituent of many plant processes as plant metabolism depends on S and a deficiency of this nutrient will cause basic metabolic impairment, which will not only reduce crop yield but also the quality of produce. For many years, little attention was paid to sulphur as a plant nutrient mainly because it has been applied to soil in incidental inputs in rainfall and volcanic emissions, and as a component of nitrogen, phosphorus and potassium fertilizers. The awareness of sulphur deficiency is increasing, as is the development of S deficiency in previously S sufficient areas in many parts of the world. In a recent report The Sulphur Institute (TSI) stated "The intensification of agricultural production per unit area, coupled with an expanding use of high-analysis, sulphur-free fertilizers or low-sulphur fertilizers, such as urea and ammoniated phosphates, is causing sulphur deficiencies to spread rapidly throughout China. The problem could be exacerbated further as sulphur dioxide emissions are increasingly controlled. If this problem is neglected, the inevitable consequences will be decreased yields and reduced efficiency of other inputs, which will, in turn, result in higher production costs. According to TSI, it is estimated that the current annual deficit for sulphur fertilizers in China is about 2.0 million tons, and will increase to 2.6 million tons annually by 2015 unless corrective measures are taken."

Non-sulphate S sources, such as elemental S, must be converted to sulphate before the plant can access it. This oxidation process is primarily carried out by autotrophic bacteria in the *Thiomonas* genus, which use reduced S sources as their energy source. The question arises as to whether these organisms, or other S oxidizers, are present in soils that have not been fertilized with elemental S. This is important if elemental S containing fertilizers are introduced into nutrient management packages. Elemental S is an almost ideal fertilizer as it contains 100% nutrients. Since micro-organisms carry out the oxidation process it is moisture and temperature dependent, as is the crop demand for S. The rate of oxidation is also dependent on the particle size of S. This means that there is great scope to manage the release rate of sulphate to the plant to

maximize plant uptake and minimize losses by surface runoff and leaching. Research carried out by Blair *et al.* (1979) has shown that plants require S and P early in growth and that oxidation rates are enhanced by intimate mixing of P and elemental S (Lefroy *et al.* 1997), which makes S inclusion into P containing fertilizers an attractive proposition. Shell Canada invented a process in 2001 to include elemental S into DAP and MAP and a patent for this was filed in 2003. This group of fertilizers, collectively known as Thiogro, is being introduced into agriculture in several countries, including China. Much of the developmental work on Thiogro has been undertaken at the International Fertilizer Development Center (IFDC) where the process has been used with pre-neutralizers (PN) and pipe cross reactors (PCR) and combined PN/PCR units with S concentration ranging up to 20%. A significant feature of the process is that the elemental S is distributed throughout the fertilizer granule. The process allows for the production of a wide range of Thiogro formulations which vary in the ratios of N, P and S and in the proportions of sulphate and elemental S they contain.

Methods

Cabbage trial Xiqiang County, 2003

This trial was conducted on a sandy loam soil of pH 4.8 with a high extractable S concentration of 23.2 µg/g. The fertilizers applied were di-ammonium phosphate (DAP), S enhanced DAP, Thiogro (SEF12) and single superphosphate (SSP). The SEF12 used had an analysis (16.2% N, 43.0% P₂O₅, 0% K₂O, 14.9% S) which contained 0.6% SO₄-S.

Rice trials 2006

Two trials were established in 2006 on sandy loam paddy soils in Jiangxi Province. S was applied at 15 kg/ha in the SEF12 (17.2:38.9:0:12S, 3.6% SO₄-S) and SSP treatments and nutrients, other than S, were balanced between treatments. A DAP treatment, which supplied 2.5 kg S/ha, was also included. Each trial occupied a total area of 1200 m² and was divided into four sections and different fertilizers applied to each section. At maturity areas of 53 m² and 60 m² were sampled from within each fertilizer treatment at the Nanfeng and Nichuan sites, respectively, and yields determined. Although the quarters were not randomized the four samples have been statistically analysed as quadruplicates. Scoring of the treatments was undertaken at the tillering, rapid growth and heading growth stages by three to five technicians. Scoring or insect damage was undertaken on a 0-10 scale with the most affected plot given a score of 10 and the least affected a score of 1 and the other plots scored relative to these two plots. At heading, 20 plants/plot were harvested and the degree of leaf damage estimated as a % of the leaf area. The major insects were rice leaf roller and brown plant hopper.

Rapeseed trials 2006

Two randomized small plot trials were established in 2006 in which DAP, SSP and SEF12 (17.2:38.9:0:12S) were compared. The fertilizers were applied at rates to deliver the same rate of P as applied in DAP (75 kg P₂O₅/ha) at Maying Sishan and at the same rate of S as applied in SSP (30 kg S/ha) at Maying Sequ (Table 6).

At both sites a DAP treatment was included.

Results

Cabbage trial Xiqiang County, 2003

There was a significant response to S in SEF12 with all granule sizes and the 2.0-0.5 mm and <0.5 mm granule sizes produced higher yields than SSP (

Table 3). Although replicate data is not available to test the statistical significance there was a lower incidence of soft rot where SEF12 was applied (18-19% reduction) and leaf disease (20-31% reduction where S was applied following a freezing event on February 7, 2003.

There is no published data on the effect of soil applied elemental S on the incidence of disease when it is applied at agricultural rates such as the 30 kg S/ha as applied here. A lower incidence of crown rot has been observed in alfalfa grown in the NW of NSW, Australia when S was applied (Blair GJ, pers. comm.).

Another interesting feature of this trial is the differential N and S utilization rates in the different treatments (Table 4). Apparent N and S utilization is the N and S content of the cabbage expressed as a % of the N or S applied in fertilizer. Apparent utilization of both N and S was highest in the SEF treatments and NUE and SUE was also higher in these treatments.

Rice trials 2006

There was no grain yield response to the sulphate applied in single superphosphate (SSP) at either site; however, there was a significant response to SEF12 at both sites (Table 5). SEF12 was superior to SSP at both sites. These differences between treatments were evident in the vigour scorings from the tillering stage. The yield differences appear to be due to the differential effect of insect and disease damage in the treatments. Scoring data indicates that the differences between treatments was evident at tillering and continued throughout the growth of the crop. Whilst there is much data on the effect of foliar applied elemental S on fungal pathogens, there is no evidence in the literature that soil applied elemental S and sulphate can have differential effects on insects and disease.

Table 3. Yield of cabbage grown at Xiajiang, Jiangxi, 2003.

Fertiliser	Yield ^A (t/ha)	Relative yield	Soft rot disease (%)	% reduction in soft rot	Leaf disease (%)	% reduction in leaf disease
DAP	24.67 c	100	61.2		54.8	
SEF12	28.94 a	117	43.2	18	35.1	20
SSP	28.27 b	114	56.6	5	35.6	19

^A Yields followed by the same letter are not significantly different from each other.

Table 4. N and S utilization rates (calculated as N and S content of cabbage as a % of the nutrient applied in fertiliser) and Nitrogen and sulfur use efficiency expressed as kg yield/kg nutrient applied in fertilizer.

Fertiliser	Apparent utilization (%)	Apparent S utilization (%)	Nitrogen Use Efficiency (NUE) (kg grain/kg N applied)	Sulfur Use Efficiency SUE) (kg grain/kg S applied)
DAP	46.9		7.7	
SEF	62.1	57.7	9.5	63.7
SSP	57.8	56.0	9.8	65.0

Table 5. Yield of rice grain (kg/ha) and degree of disease and insect damage in trials conducted in Jiangxi Province, 2006.

Treatment	Nanfeng County, Shantian Town				Nichuan County		
	DM Yield (kg/ha)	RAE	Disease and insect score at heading (10=most severe)	Rice leaf roller damage (%)	DM Yield (kg/ha)	RAE	Disease and insect score at heading (10=most severe)
DAP	7868 b	100	10	29.4	6560 b	100	10
SEF12	8686 a	110	1	3.6	7453 a	114	1
SSP	7886 b	100	7	23.1	6790 b	104	8

Rapeseed trials 2006

At the Maying Shishan site there was a significant response to S in SSP and SEF12 (Table 6) with no significant difference between them despite an additional 41 kg S/ha being applied in the SSP treatment compared to the SEF12 treatment. At the Maying Sequ site (Table 6) SEF12 out yielded SSP when applied at the same S rate. It is unlikely that the higher yield was due to the additional P applied in the SEF12 as there was no significant difference in yield between the SSP and DAP treatments, with each receiving 98 kg P₂O₅/ha.

Table 6. Nutrient application rates made in each treatment and yield of rapeseed (kg/ha), Jiangxi Province 2006/7.

Fertilizer	Nutrients applied (kg/ha)			Fertilizer rate (kg/ha)	DM yield ^A (kg/ha)	Nutrients applied (kg/ha)	Fertilizer rate (kg /ha)			DM yield ^A (kg/ha)
	N	P ₂ O ₅	S			N	P ₂ O ₅	S		
	(-----Maying Sishan-----)					(-----Maying Sequ-----)				
DAP	150	75	0	163	2345 c	150	98	0	212	2476 bc
SEF12	150	75	23	192	2453 ab	150	98	30	250	2686 a
SSP	150	75	64	536	2607 a	150	35	30	250	2358 c

^A Yields followed by the same letter are not significantly different at 5% probability according to Duncan's multiple range test.

Conclusion

Differential response to soil applied sulphate and elemental S have been recorded in cabbage and flooded rice with less soft rot disease in cabbage and less disease and insect damage in rice when elemental S was applied. No mechanism for this can be found in the literature. Elemental S was superior to sulphate-S in one of two trials on rapeseed. These trials suggest that elemental S containing fertilizers require further investigation in both upland and flooded crops.

References

- Blair GJ, Momuat EO, Mamaril CP (1979) Sulfur nutrition of Rice. II. Effect of source and rate of S on growth and yield under flooded conditions. *Agronomy Journal* **71**, 477-480.
- Lefroy RDB, Sholeh, Blair G (1997) Influence of sulfur and phosphorus placement, and sulfur particle size, on elemental sulfur oxidation and the growth response of maize (*Zea mays*). *Australian Journal of Agricultural Research* **48**, 485-495

Effects of Australian rice farming systems on soil organic carbon concentrations

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Abstract

Considering a shift from pasture based conservative rice farming to intensive rice cultivation in rotations with winter and/or summer crops (wheat, barley, oats, soybeans, sorghum, and corn), an investigation was conducted during 1999-2006 to benchmark different rice paddocks for monitoring changes in soil organic carbon (SOC) and other important properties. Composite samples were collected from the surface (0-10 cm) and sub-surface (10-30 cm) layers of 250 commercial rice paddocks and 50 experimental plots. Sampling sites were GPS marked for future use. Analysis of appropriately processed soil samples was done for SOC, EC_{1:5}, pH_{1:5} (0.01M CaCl₂), and CEC. Another investigation was also conducted to compare the effects of two native land uses (grassland, and treeland) with cultivated soils. Analytical results indicated a gradual decrease in SOC with increased rice cropping intensity. Surface layer of red brown earth (RBE) paddocks showed comparatively lower SOC and pH than its transitional red brown earth (TRBE) and grey (Grey) soil counterparts. This was also true for the effects of the native land uses. Regardless of soils, sampled rice paddocks were non-saline for both depths. Surface layer CEC of grey soil paddocks was significantly more than those of the TRBE and the RBE paddocks. However, this variation was less in deeper layers.

Key Words

Rice soils, soil fertility and productivity, soil analysis, soil changes, farming practices, rice cropping.

Introduction

Commercial cultivation of rice in Australia commenced in late 1920s. Since then the area under rice has increased gradually with the development of irrigation in semi-arid areas of Murrumbidgee and Murray valleys of south western NSW, notwithstanding fluctuations due to the available irrigation water each year and recent droughts. In early decades, irrigated pastures (*Trifolium subterraneum*) based rice was the predominant farming system. Irrigated pastures helped improve nitrogen fertility of the common rice soils (Williams and Raupach 1983), most of which were inherently fragile and had low productive potential. Advent of high yielding fertiliser responsive rice varieties during the late 1960s, however, boosted rice productivity tremendously and caused notable diversification and intensification of the Australian rice farming systems.

Comparatively high profitability of the Australian rice farming systems depends upon their relatively high yields (9-10 t/ha unhusked rice). Application of 180-200 kg N/ha to rice grown in non-pasture cropping systems is now a common practice (Gill 2009). This implies that appropriate management and monitoring of rice soils for their fertility and productivity is necessary to sustain high grain yields. Different viewpoints (Karlen *et al.* 1997; Dalal *et al.* 2003) on quality and health of desirable soil conditions for highly productive land uses indicate that maintenance of optimum soil organic matter (SOM) concentrations in rice soils is of paramount importance because of its role as a store house for supplying native soil N, which accounts for approximately half of total N uptake of rice crops. In addition, SOM causes significant chemical, biological and physical effects on other beneficial soil functions. Available research information related to the impact of predominant Australian rice farming systems on SOC is limited and not quantitative. An investigation was, thus, carried out to benchmark and monitor periodically selected rice paddocks to ascertain changes in SOC of major rice soils due to the common rice farming systems.

Methods

This paper is based on investigations carried out during 1999-2006. We aimed at having quantitative assessment of the current status and benchmarking sites for monitoring temporal changes in total organic carbon content of the soils typical to the common Australian rice farming systems. A parallel study was also conducted to compare total organic carbon concentrations of soils common to rice farming systems and the two native land uses (grasslands, and treeland).

Site selection

Study sites were selected based on a written survey and interviews with numerous farmers. More than 282 paddocks and 50 experimental plots were chosen across the major rice growing districts of Murray and Murrumbidgee valleys considering information collected on each paddock such as the differences in rice cultivation intensity, three soil types [(grey Vertosols, red brown earth Chromosols (RBE), and mixture of these two called transitional red brown earths (TRBE)] typical of most rice paddocks, short and long term history of rice farming systems, fertilizer use, water use, average rice productivity, rice varieties grown, management practices, use of rice check, soil and plant analysis (panicle initiation NIR test) for diagnosing crop needs for fertilizers etc. Similarly, 96 sites were selected comprising the two native land uses (grass land, and treeland) and the surrounding cultivated soils across the major rice growing areas and districts.

Soil sampling

Using a mechanical corer, surface (0-10 cm) and sub-surface (10-30 cm) soil samples were collected from each of the selected paddocks before their fertilization for growing rice. Each sample was a composite of 20 cores taken randomly from different locations within each rice paddock. All of the 20 locations in each rice paddock were marked with GPS for future monitoring. Each sample was air dried at 40°C before processing (grinding, sieving) and stored in large polythene bottles. Similar procedure was used for sampling from the grassland and the treeland sites without GPS markings. However, the soil at each location was sampled to 50 cm depth in five equal layers of 10 cm. Sampling was done with soil augers due to accessibility problems. Composite samples for each of the five depths were prepared by mixing ten samples from each location.

Soil analysis

Appropriately processed soil samples were analyzed for soil acidity by measuring pH of soil in 0.01M CaCl₂ solution and soil salinity by determining EC of soil in de-ionized water using 1:5 soil-solution ratios (w/v) following procedures of Rayment and Higginson (1992). Total soil organic C and N were determined by the dry combustion using LECO CNS-2000 Analyzer. The cation exchange capacity (CEC) was determined following the method of Anderson and Ingram (1993).

Statistical analysis

Variation in different soil properties due to the given land uses, rice farming systems, soil types and depths were analyzed using analysis of variance, considering land uses, soil types, farming systems, and depths as definite variables but sites as random variables.

Results

Data on average SOC concentrations in various layers of the three soils indicate (Table 1) significant differences due to their land uses. Regardless of the soil types and their land uses, maximum accumulation of SOC was found to occur in the surface (0-10 cm) layer. Average SOC concentrations due to the treeland use were considerably higher in layers between 0-30 cm depths as compared to the other two land uses. This is attributed to the minimum soil disturbance, regular additions of litter materials to the surface soil, and conservative effects of tree canopies associated with beneficial modifications in micro-climate for protecting soil organic materials from decomposition.

For each of the three land uses, SOC averages of the Grey and the TRBE were significantly greater than the RBE for 0-10 cm and 10-20 cm depths. Experimental results (Table 1) also demonstrate beneficial influence of irrigated cropping in building SOM up. A comparison between irrigated cropping and grassland shows that the former was effective in increasing SOC more than the latter. This effect was especially pronounced in 0-10 cm layer. For example, SOC means of 1.75, 1.70, and 1.44 g/100g soil for the Grey, TRBE, and RBE under irrigated cropping were significantly greater than their corresponding averages of 1.45, 1.12, and 1.33 g/100g soil under grassland use, respectively.

Table 1. Mean SOC concentrations (g/100g) in different layers of the three soil types under the three given land uses. (Significance of differences between soil types under different land uses using Tukey's post-hoc test indicate that means with different letters are significantly different at P=0.05).

Soil layer (cm)	Irrigated cropping			Treeland			Grassland		
	Grey	RBE	TRBE	Grey	RBE	TRBE	Grey	RBE	TRBE
0-10	1.75a	1.44b	1.70a	3.46a	2.45b	2.95c	1.45a	1.12b	1.33c
10-20	1.65a	1.32b	1.52c	2.92a	1.88b	1.82b	1.28a	0.96b	1.15c
20-30	1.41a	1.13b	1.35c	1.81a	1.55b	1.73a	0.86a	0.74a	0.78a
30-40	0.90a	0.68b	0.80a	0.84a	0.74a	0.82a	0.65a	0.62a	0.72a
40-50	0.69a	0.58a	0.63a	0.78a	0.54b	0.70a	0.47a	0.50a	0.52a

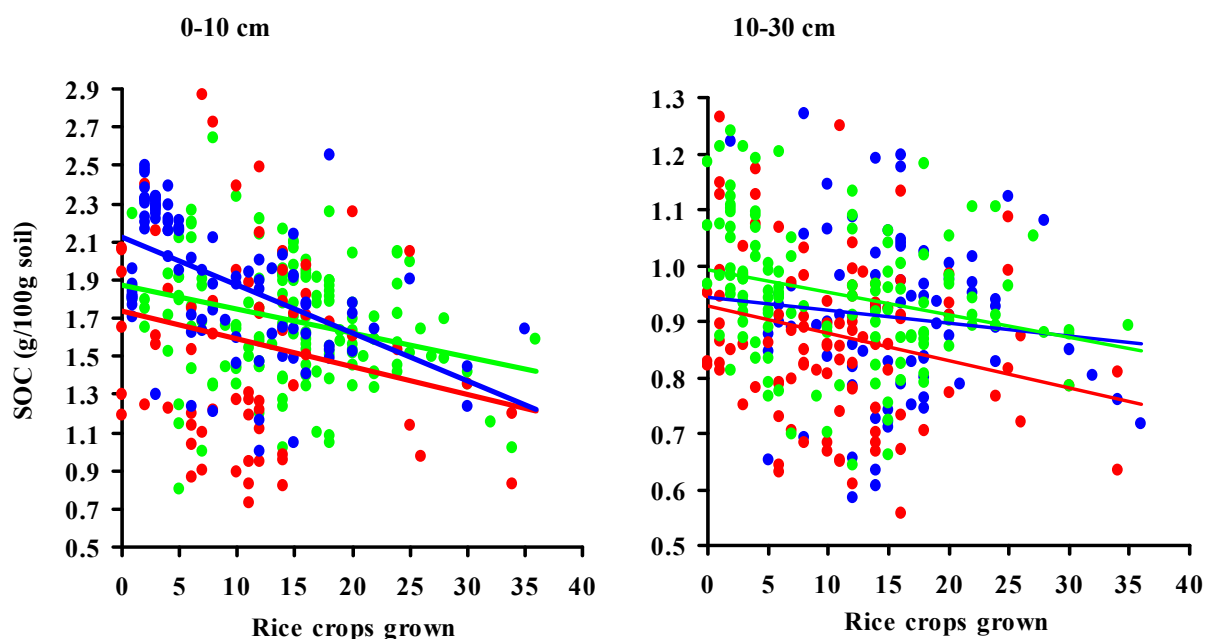


Figure 1. Effects of rice cropping intensity on SOC concentrations in the surface (0-10 cm) and sub-surface (10-30 cm) layers of the RBE (red), TRBE (blue) and Grey (green) soils rice paddocks.

Table 2. Important statistical parameters of SOC, EC, pH, CEC and C:N ratio for the surface and sub-surface soil layers of the common three soils.

Statistical parameters	Surface soil (0-10 cm)			Sub-surface layer (10-30 cm)		
	Grey	RBE	TRBE	Grey	RBE	TRBE
Soil organic carbon (g/100g soil)						
Mean	1.69	1.57	1.91	0.91	0.87	0.95
Median	1.66	1.54	1.91	0.91	0.86	0.95
SD	0.33	0.58	0.35	0.15	0.15	0.12
Percent variation	19.60	36.60	18.43	15.99	16.81	12.51
EC _{1:5} (dS/m)						
Mean	0.17	0.11	0.15	0.21	0.14	0.18
Median	0.15	0.10	0.13	0.17	0.12	0.13
SD	0.08	0.05	0.14	0.14	0.08	0.19
Percent variation	50.54	40.90	90.79	68.94	57.04	104.23
pH _{1:5} (0.01M CaCl ₂)						
Mean	5.77	5.26	5.25	6.81	6.42	6.62
Median	5.76	5.09	5.25	6.85	6.26	6.48
SD	0.74	0.73	0.59	0.64	0.52	0.56
Percent variation	50.54	13.92	11.23	9.33	8.02	8.46
CEC ₍₊₎ (mol/kg soil)						
Mean	20.24	12.53	13.23	25.61	17.86	23.35
Median	20.33	12.50	12.00	25.99	16.95	22.45
SD	7.20	4.28	5.48	6.79	4.26	6.84
Percent variation	35.58	34.19	18.43	26.51	23.85	29.30
C:N ratio						
Mean	10.03	10.62	10.52	8.26	8.53	8.36
Median	9.76	10.83	10.30	8.06	8.16	8.30
SD	1.04	1.09	1.31	0.98	1.15	1.22
Percent variation	10.33	10.28	12.45	11.88	13.52	14.61

Variations in SOC concentrations of 30-40 cm and 40-50 cm layers were less remarkable except comparatively higher SOC averages for the TRBE and the grey soils under treeland use. Averages of SOC in the RBE were found to be lower than those for the TRBE and the grey soils under each of the three land uses, most likely due to its coarse textured surface layers considered relatively conducive for rapid decomposition of soil organic materials (Gill 2009).

Distribution of SOC concentrations of the three soils due to the intensity of rice cultivation (Figure 1) shows a notable diversity and variation, most likely due to the integrated effects of different rice farming systems, management practices, soil types, past and present history of land use of sampled paddocks. A consistent trend of decreasing SOC with increased rice cropping in the three soils is very clear. Notwithstanding this observation, average SOC concentrations in RBE paddocks are lower than those of the TRBE and grey soils (Table 2). This clearly demonstrates similarity to observations made in SOC data (Table 1) on land use effects. The differences in the sub-surface layer of the three soil types were comparatively less marked. Data (Table 2) on average EC of different paddocks indicate no major differences in salinity of both the surface and sub-surface layers of the three soils. All the paddocks were tested non-saline and are attributed to the leaching caused by flooded conditions for rice cropping. The soil acidity as measured by pH indicated (Table 2) that surface layer of the three soils are considerably more acidic than their sub-surface layer. Both the layers of the grey soils were less acidic than those of the RBE and the TRBE soils.

Average CEC of both the surface and sub-surface layers of the grey soil rice paddocks was significantly more than those with the RBE and the TRBE. However, CEC of sub-surface soil was more than the surface soil layer in all of the three soils. This confirms relatively higher clay contents in surface layer of the grey soil rice paddocks than those of the RBE and the TRBE. Similar was the observation for all of the three soils as CEC of deeper (10-30 cm) soil layer was greater than their surface (0-10 cm) soil layer due to its greater clay contents. Data on mean and median C:N ratios of both the surface and sub-surface layers did not differ much due to different soils. But the mean and median of sub-soil layer for each of the three soils were about 20 per cent narrower than the surface layer. Variation between the mean and median values of different soil parameters (Table 2) was not significant indicating integrity and normal distribution of experimental data.

Conclusion

The SOC concentrations showed gradual decline with increased intensity of rice cultivation. Pasture based rice paddocks were having more SOC than those where rice is grown in rotation with winter cereals during the recent past. Rice paddocks with the TRBE and the grey soils had significantly more SOC in the surface (0-10 cm) layer than those of the RBE. This difference was not observed in sub surface layers. This was also true in a parallel investigation on the impact of different land uses on SOC concentrations. Regardless of soil types, sampled rice paddocks were non-saline. The grey soil paddocks were comparatively less acidic than those of the TRBE and the RBE. The surface layer CEC of the grey soil paddocks was significantly more than those of the TRBE and the RBE paddocks. The sub-surface layer CEC of all the three soils was increased significantly. The C:N ratios of the three soils were almost similar but sub-surface C:N ratios relatively narrower than their surface soils counterparts. Results of this investigation indicate the presence of a diverse potential for developing management practices suitable for sustaining fertility and productivity of different soil rice paddocks and increasing productive performance of important agricultural inputs.

References

- Anderson JM, Ingram JSI (1993) 'Tropical Soil Biology and Fertility: A Handbook of Methods, Second edition'. (CAB International: Wallingford).
- Dalal RC, Eberhard R, Grantham T, Mayer DG (2003) Application of sustainability indicators, organic matter and electrical conductivity to resource management on the northern grains region. *Australian Journal of Experimental Agriculture* **43**, 253-259.
- Gill HS (2009) Impact of Australian rice farming systems on the soil changes. A survey on rice soils sustainability investigation. (Unpublished results)
- Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF, Schumann GF (1997) Soil quality: a concept, definition and framework for evaluation. *Soil Science Society of America Journal* **61**, 4-10.
- Rayment RE, Higginson FR (1992) 'Australian Laboratory Handbook of Soil and Water Chemical Methods'. (Inkata Press: Melbourne).
- Williams CH, Raupach M (1993) Plant nutrients in Australian soils. In 'Soils: an Australian viewpoint' (Division of Soils, CSIRO), pp. 777-793. (Melbourne/Academic Press: London).

Effects of cultivation on phosphorus exports from irrigated pastures

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Abstract

Soil, soil water and overland flow were measured on border-check irrigation bays that had received various levels of soil disturbance (i.e. cultivation) aimed at reducing potential P mobilisation from surface soil (0-20 mm) over a four year period.

In general, increasing levels of soil disturbance lowered surface soil Olsen P, Colwell P, Organic P and Calcium Chloride Extractable P although the strength of the relationships diminished with time. Increasing levels of soil disturbance also lowered soil water Dissolved Reactive P (DRP) and Total Dissolved P (TDP). However, these effects did not translate to overland flow. In the first year there was an apparent reduction in overland flow DRP, TDP and Total P with increasing soil disturbance ($P=0.041$, $P=0.012$, $P=0.025$) but that trend dissipated quickly with time ($P=0.05$). There was no such trend in subsequent years.

These experiments were undertaken on commercial farms. It would appear that while cultivation lessened background or 'systematic' nutrient exports, critical decisions of the land managers such as applications of additional N fertiliser and grazing affected expression of those changes. This study emphasises the need to develop improved management systems rather than simply improved management practices if we are to meaningfully address nutrient exports from pasture based grazing.

Key Words

Runoff, water quality, destratification

Introduction

Excessive phosphorus (P) and nitrogen (N) concentrations in streams draining agricultural catchments and their receiving waters are a world-wide problem. Pasture based grazing is a major landuse in Australia and New Zealand with P exported from these systems contributing to the eutrophication of national assets including the Gippsland Lakes and associated wetlands (Grayson *et al.* 2001). In perennial grasslands surface-applied P amendments, detrital material and wastes from grazing animals can increase P concentrations, lower P adsorptive capacity in surface soils (Dougherty *et al.* 2006) and increase P export potential (Pierson *et al.* 2001). Cultivation is one way of lessening P availability in surface soils (sometimes referred to as P destratification) and therein P exports, although most such studies have been undertaken at the plot scale.

Laser grading (i.e. leveling of pasture soils in preparation for border-check irrigation) is an extreme form of soil disturbance that has been shown to lessen Total Dissolved P (TDP), Total Dissolved N (TDN), Total P (TP) and Total N (TN) exports in wetting-front runoff by 40, 29, 41 and 36% respectively (Nash *et al.* 2007a; Nash *et al.* 2007b). In this study we use a field scale experiment to investigate the effectiveness of a series of lower impact treatments that might be used as part of a pasture renovation program to lower surface soil P and N concentrations and nutrient exports. The specific aims of the study were: (a) to compare management interventions with differing levels of soil disturbance that may decrease P mobilisation and decrease nutrient concentrations in overland flow; and (b) to investigate the longevity of such management interventions and factors that may affect them.

Methods

The experiment commenced in 2003/2004 when 16 irrigation bays (on three farms) in the Macalister Irrigation District (MID) of south eastern Australia were selected and prepared (i.e. covariate soil sampling and irrigation sampling) for testing. A control and five treatments ((i) direct drilling of pasture without spraying with herbicide; (ii) direct drilling following spraying; (iii) spraying followed by aeration and direct drilling; (iv) spraying followed by cultivation to 100 mm and direct drilling; and (v) spraying followed by cultivation to 200 mm and direct drilling) were applied to groups of six bays on each of two farms in 2004/05. The following year an additional three of a group of four bays were treated with the most disruptive treatments (iii, iv and v).

Pasture on the bays contained perennial ryegrass (*Lolium perenne*), white clover (*Trifolium repens*), tall fescue (*Festuca arundinacea* cv. Advance, one bay only) and assorted invasive species including dock

(*Rumex spp.*) and distichum (*Paspalum paspaloides*). The soil type was a Vertic, Grey Sodosol (Natrigeralf). Twice yearly a basal dressing of fertiliser (containing ca. 11, 25, 30 and 15 kg/ha of N, P, K and S, respectively, per application) was applied to the field sites.

Where possible, farms were sampled once in late spring-early summer and once in late summer-early autumn. As fertiliser application and grazing affect runoff nutrient concentrations, sampling occurred at least five weeks after P fertiliser applications and where possible, sampling did not occur less than one week after grazing.

Surface soil samples were recovered a day or two after irrigation when surface water had receded. Fresh faecal deposits were avoided to minimise variability from the potential nutrient source. The soil samples were taken from a 0-20 mm depth at the top of the bays adjacent to the irrigation water inlet and at 50 m intervals thereafter. A minimum of 30 soil cores were extracted using a stainless steel soil probe (25 mm I.D. x 20 mm) and bulked to obtain a composite sample for each bay sampling point. Cores were collected from a transect perpendicular to the check-banks within 2 m of the sampling point. The soil cores were stored (<4°C) in polyurethane bags and transported to the laboratory within 4 hours of collection.

At the laboratory the composite soil samples were thoroughly hand-mixed and bulked prior to preparation for soil and soil water analyses. A single bulked sample, representing the bay in question, was then prepared for soil analyses. Soils were analysed for Olsen P and Colwell P using standard methods (Rayment and Higginson 1992). Organic P was estimated as the additional P released after persulfate digestion of the Colwell P extract and measured using the traditional phosphomolybdenum blue chemistry. Calcium Chloride Extractable P was measured after a 1 hr extraction using a 1:10 ratio of soil to 0.01M CaCl₂ solution, followed by filtration through a Whatman (Maidstone, UK) #2 filter paper. Soil water was extracted from a sub-sample of the soil mixture (Toifl *et al.* 2003) on the same day as sample collection and before the soil mixture was dried. Soil water was analysed for EC, pH, Dissolved Reactive P (DRP) and Total Dissolved P (TDP).

Overland flow samples were collected from the irrigation immediately preceding soil sampling. As was the case for soils, overland flow samples were taken at the top of the bay adjacent to the irrigation water inlet and at 50 m intervals thereafter. Overland flow was sampled at the wetting front (i.e. within 2 m of the actual water front). At each sampling location at least 14 columns of water, each ca. 70 cm³, were recovered (Nash *et al.* 2004). Filtered water samples were tested for DRP and TDP (<0.45 µm) and unfiltered samples for Total P (TP) (Lachat Instruments 2009). Dissolved Organic P (DOP) was calculated as the difference between TDP and DRP.

Results

Selected results are presented in Figures 1, 2 and 3. Surface soil (0-20 mm) Olsen P and Colwell P varied between sites, treatments and years. In both cases the lowest Olsen P and Colwell P concentrations were in the 100 and 200 mm cultivation treatments. Soil Organic P did not vary between sites but did vary between treatments and years. Soil Calcium Chloride Extractable P also varied between sites, treatment and years.

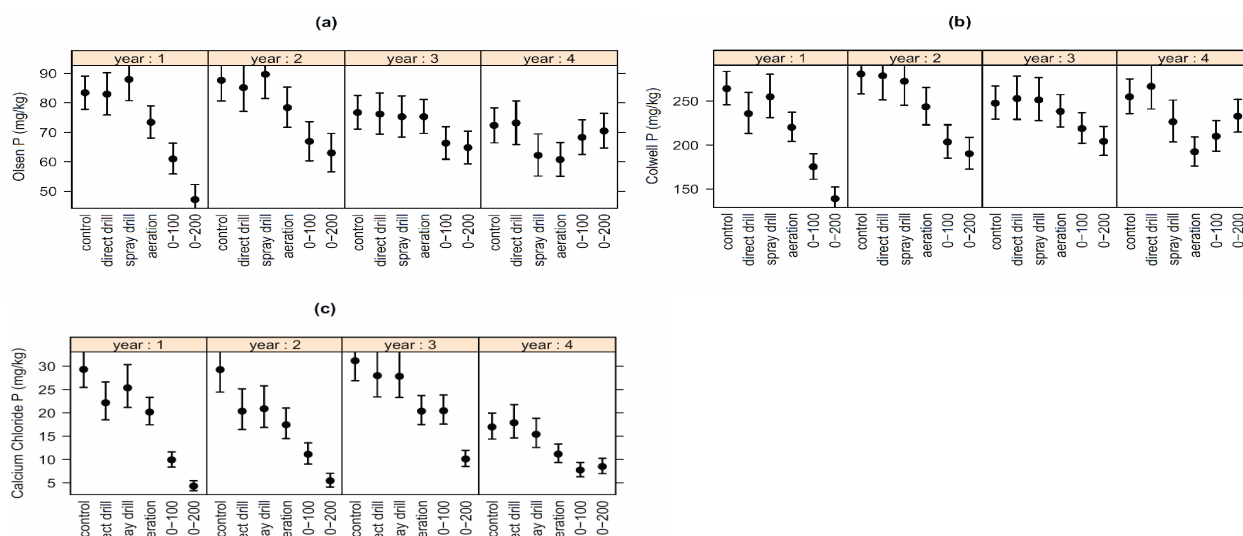


Figure 1. Changes in soil (0-20 mm) (a) Olsen P, (b) Colwell P and (c) Calcium Chloride Extractable P for selected treatments between years.

Soil water analyses were in broad agreement with the soil test results. Soil water DRP varied between sites, between sampling positions in the bay and between treatments, ranging from 3.7 mg P/L for the control to 1.9 mg P/L for the 200 mm cultivation treatment. Soil water TDP was also affected by site, sampling position and treatment. Like soil water DRP, TDP did not vary between years but the effects of treatment did. Soil water DOP (i.e. TDP-DRP) varied with position and treatment.

There were fewer factors affecting the overland flow data compared to either the soil or soil water data. Overland flow DRP was affected by sampling position but unaffected by treatment or year. TDP and TP were also affected by sampling position in the bay.

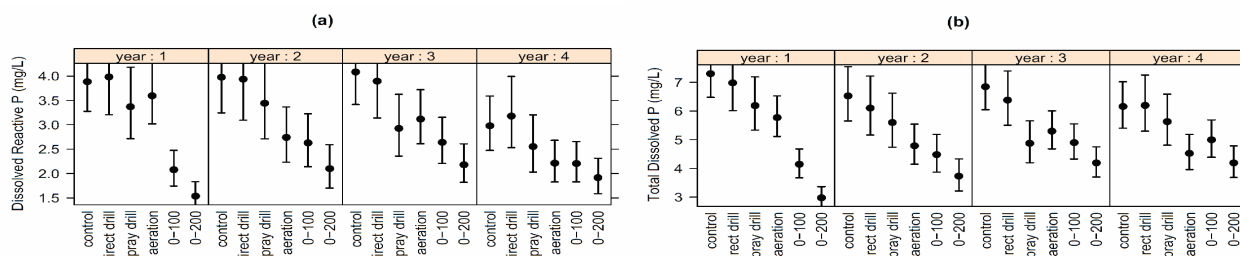


Figure 2. Changes in soil water (0-20 mm) (a) Dissolved Reactive P and (b) Total Dissolved P.

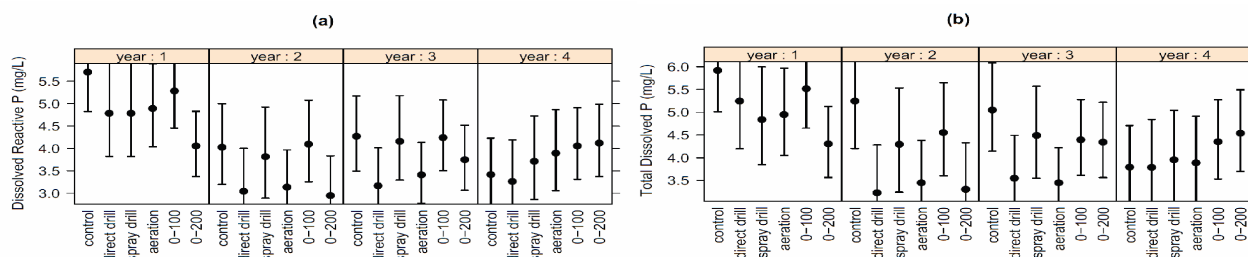


Figure 3. Changes in overland flow (a) Dissolved Reactive P and (b) Total Dissolved P.

Discussion

This study shows that cultivating soil, as commonly would occur during pasture renovation on some Victorian dairy farms, lowers the ‘systematic’ or ‘background’ phosphorus export potential. Such cultivation decreased soil Olsen P, Colwell P, Calcium Chloride Extractable P and Organic P as well as soil water DRP and TDP, over the four years of the study. However, this study has also shown that while reduced ‘systematic’ export potential achieved by cultivation may be important, on commercial farms there are critical decisions, some of which are under management control, that may be equally or more important in determining nutrient exports.

For logistical reasons, even within one farm, grazing could not occur simultaneously across all the bays used for the study and the number of grazing days varied heavily from year to year. It would appear that the variability in the time between grazing and when sampling was undertaken, the between site, between bay and between year variability, the repeated sampling of the same bays and the low degrees of freedom of the overall experiment, resulted in the beneficial effects of cultivation, demonstrated through the soil and water tests, not being expressed in the overland flow results.

These data are from commercial farms operating in a commercial environment. If improved or better management practices do not measurably lessen nutrient exports in commercial systems then it is important it is documented. What this project has shown is that even when we lessen ‘systematic’ phosphorus export potential through cultivation, critical ‘incidents’ (i.e. management decisions) can potentially nullify much of those gains. Clearly, we need to develop sustainable farming systems rather than simply improve management practices if we are to address complex issues such as nutrient exports from agriculture.

Acknowledgements

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References

- Dougherty WJ, Nash DM, Chittleborough DJ, Cox JW, Fleming NK (2006) Stratification, forms and mobility of phosphorus in topsoil of a Chromosol used for dairying. *Australian Journal of Soil Research* **44**, 277-284.
- Grayson RB, Tan KS, Western A (2001) Estimation of sediment and nutrient loads into the Gippsland Lakes. CSIRO and University of Melbourne, Final Report No. CEAH 2/01, Melbourne, Australia.
- Lachat Instruments (2009) Methods for automated ion analyzers. Hach Company, Loveland, Colorado, USA.
- Nash D, Hannah M, Barlow K, Robertson F, Mathers N, Butler C, Horton J (2007a) A comparison of some surface soil phosphorus tests that could be used to assess P export potential. *Australian Journal of Soil Research* **45**, 397-400.
- Nash DM, Hannah M, Clemow L, Halliwell D, Webb BJ, Chapman D (2004) A field study of phosphorus mobilisation from commercial fertilisers. *Australian Journal of Soil Research* **42**, 313-320.
- Nash DM, Webb B, Hannah M, Adeloju S, Toifl M, Barlow K, Robertson F, Roddick F, Porter N (2007b) Changes in nitrogen and phosphorus concentrations in soil, soil water and surface run-off following grading of irrigation bays used for intensive grazing. *Soil Use and Management* **23**, 374-383.
- Pierson ST, Cabrera ML, Evanylo GK, Kuykendall HA, Hoveland CS, McCann MA, West LT (2001) Phosphorus and ammonium concentrations in surface runoff from grasslands fertilized with broiler litter. *Journal of Environmental Quality* **30**, 1784-1789.
- Rayment GE, Higginson FR (1992) 'Australian Laboratory Handbook of Soil and Water Chemical Methods.' (Inkata Press: Melbourne, Australia).
- Toifl M, Nash D, Roddick F, Porter N (2003) Effect of centrifuge conditions on water and total dissolved phosphorus extraction from rewet and field wet soils. *Australian Journal of Soil Research* **41**, 1533-1542.

Effects of different organic fertilizers on soil microbial biomass and peanut yield

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Abstract

A pot experiment was conducted to investigate the effects of different organic fertilizers on soil microbial biomass and peanut yield using plate counting and Denaturing Gradient Gel Electrophoresis (DGGE) methods. The treatments included a) no fertilization (CK), b) chemical fertilizer, c) pig manure, d) cattle manure, e) organic compound fertilizer of monosodium glutamate, and f) chicken manure. Results have shown that both the economic and biological yield of peanut was improved by applying fertilizers, with highest yields being found for applying a compound organic fertilizer of monosodium glutamate. On average, the economic and biological yield in all treatments with applications of either chemical or organic fertilizers increased by 73.5% and 50.0%, respectively, compared with CK. Total amounts of bacteria, epiphyte and actinomyces in the treatment of applying chicken manure were the highest among different fertilizer treatments, while they differed little among other treatments. Results from PCR amplification of soil DNA and DGGE analysis indicated significant differences in soil microbial composition and diversity among different chemical and organic fertilizer treatments. Different organic fertilizers affect the biomass of soil microbes as well as their diversity trait.

Key Words

Peanut, yield, organic fertilizer, soil microbial biomass, DGGE.

Introduction

Application of organic fertilizers is one of important practical measures to improve soil fertility. In addition to providing necessary nutrients for crops and improving soil physico-chemical properties, organic fertilizer is able to enhance soil microbial activity of soil, such as improving activity of soil enzymes and increasing soil microbial biomass (Ren *et al.* 1996; Sun 2003; Lv *et al.* 2005). However, a lot of soil microbes are at nutrition-deficient or un-culturable levels under natural environmental conditions. The measurement of total microbial biomass with rich beef broth in the laboratory will introduce a great error due to the fact that a lot of nutrient-deficient microbes cannot grow. In general, traditional plate culture method can only separate 0.1%~1% of soil microbes present, and cannot reflect the original status of soil microbial diversity (Cai and Liao 2002; Vigdis and Lisc 2002; Luo *et al.* 2003). With the advances in the application of molecular techniques, PCR-based techniques have been widely used (e.g. Bossio *et al.* 2005; Zhang *et al.* 2007). The objective of this study was to examine the effects of application of organic manures on peanut production and the impacts on soil microbial biomass and diversity of soil microbe composition using combined plate counting and PCR-based Denaturing Gradient Gel Electrophoresis (DGGE) methods.

Methods

Soil

A clayey grey-yellow soil collected from Xitou village, Baisha town, Miuhou county was used in this study. Soil pH was 5.3, while total N, P and K were 1.26, 0.27 and 4.3 g/kg respectively. Available N, P and K amounted to 183.1, 39.3 and 25.1 mg/kg respectively. Soil organic matter was 10.4 g/kg. Basic properties of main organic fertilizers were shown in Table 1.

Table 1. Basic properties of organic fertilizers used in this study

Organic fertilizer ^a	OM (g/kg)	Total N (g/kg)	Total P (g/kg)	Total K (g/kg)	pH
Organic compound fertilizer of monosodium glutamate	180	105.0	13.0	30.0	6.1
Pig manure	500	8.8	26.0	9.5	8.7
Cattle manure	410	13.0	9.0	11.0	6.9
Chicken manure	410	29.3	36.8	18.7	8.3

Treatments

The experiment included six treatments with four replications and fully-randomized arrangements. The treatments were: a) no fertilization (CK); b) chemical fertilizer; c) pig manure; d) cattle manure; e) organic compound fertilizer of monosodium glutamate; and f) chicken manure. Plastic pots (26 x 22.5 x 29 cm) were used for this pot experiment. Each pot contained 7.5 kg soil, for each kg soil, 0.1g N was supplied, and N:P₂O₅:K₂O ratios were 5:4:6. The equivalent N, P and K were given to each treatment. The corresponding amounts of chemical fertilizers (carbamide, potassium chloride, potassium dihydrogen phosphate) were supplemented to the treatments of organic manures to make up the deficient part of N, P and K. Fertilizers were fully mixed with soil on the plastic sheet, and then loaded into pots. Seven peanuts were planted, but only three seedlings were finally selected. Plants were harvested and yield of peanuts were measured four months after planting.

DGGE Analysis of soil microbial diversity

Total DNA of soil microbe was amplified by using 16s rDNA V3 primers that No.1 is 5-ATTACCGCGGCTGCTGG-3, No.2 is 5-(GC)-CCTACGGGAGGCAGCAG-3 (Zhao *et al.* 2005). The reaction system was that 10×amplified buffer solution 2.5μL of 25 mM MgCl₂, 2μL of 2.5 mM dNTP, No.1 primer and No.2 primer was 0.5μL, respectively. The template DNA was 20-40 ng, add water to 24.5 μL of Taq enzyme was 0.5 μL (5U/μL) and the total volume is 25 μL. The procedure for amplification was denaturalized at 95 °C for 5min, 94 °C for 1min, 50 °C for 1min, 72 °C for 40s, 30 circulations, and then extended 10min at 72 °C, and stored at 4 °C. DGGE was carried out on the amplified outcome of 16S rDNA (V3 selection) by Dcode universal mutation detection system (Bio-Rad). Denaturant concentration is prepared from 30% to 70% with 8% polyacrylamide gel electrophoresis, the denaturant concentration increased from upper to underside. When the gel solidified, it was pre-heated to 60 °C. 20μL PCR amplified outcome and 2×loading buffer(70% butter, 0.05% bromophenol blue, 0.05% dimethylbenzene) were loaded into each hole, and electrophoreses was done for 16h at 70V. The gel was dyed 30min with 1000 times dilution of syber green after electrophoresis. The dyed gel is observed and pictured through imaging system (Bio-Rad).

Results

Effect of different treatments on peanut yield

Table 2 has shown that peanut legume yields increased significantly (by 42.8% - 73.5%) in all fertilizer treatments, compared with CK. The order of legume yield was: organic compound fertilizer of monosodium glutamate > pig manure > cattle manure > chemical fertilizer > chicken manure. Total peanut biomass also increased significantly (28.3-50.0%) in all fertilizer treatments compared with CK, with the order: organic compound fertilizer of monosodium glutamate > chemical fertilizer > pig manure > chicken manure > cattle manure (Table 2).

Table 2. Effects of different fertilizer treatments on the yield of peanut^a

Treatment	Legume yield (g/basin)	Increase than CK (%)	Biological yield (g/basin)	Increase than CK (%)
CK	7.2±1.11b	-	18.9±1.46c	-
Inorganic fertilizer	10.5±1.25a	45.17	28.1±3.31ab	48.41
Pig manure	11.3±2.92a	55.52	27.0±4.73 ab	42.72
Cattle manure	10.8±1.06 a	49.31	24.3±0.66b	28.31
Organic compound fertilizer of monosodium glutamate	12.6±0.90 a	73.45	28.4±2.25a	50.00
Chicken manure	10.4±1.30 a	42.76	25.6±0.92ab	35.32

^aData followed by the same letter are not significant (P > 0.05).

Effect of different treatments on soil microbial biomass using plant count method

Except organic compound fertilizer of monosodium glutamate, all fertilizer treatments increased total bacterial counts compared with CK, with a biggest increase in the chicken manure treatment (by 433%) (Table 3). All fertilizer treatments increased fungi counts except for the cattle manure treatment, also with a biggest increase in the chicken manure treatment (717%) (Table 3). Soil actinomyces increased in population compared with CK in all treatments except for the chemical fertilizer treatment.

Effect of different treatments on soil microbial community composition using DGGE

The amplified products of soil total microbe DNA 16SrDNA V3 of different fertilizer treatments were

analyzed by Denatured Gradient Gel Electrophoresis (DGGE) (Figure 1). The DGGE bands of DNA samples from different fertilizer treatments could be well separated, where the intensity and transferring rates were not the same. Meanwhile, many common bands were found in different treatments, but the intensity was different. There were deeper colour bands to compare to other samples when samples were from the treatments applying pig manure, chicken manure, and organic compound fertilizer of monosodium glutamate. It demonstrated that using all kinds of organic fertilizers promoted the increase of some microbial biomass to compare with the treatment of CK and chemical fertilizer. The band patterns appeared different when different organic fertilizers were applied to the soil. For example, dark colour band in treatment of pig manure appears No.1 strip, but in that of organic compound fertilizer of monosodium glutamate appears both No.3 and No.4. Maybe, the effects of soil microbial diversity have been affected by some special substance in pig manure or organic compound fertilizer of monosodium glutamate. However, the correlated degree needs to be further investigated. The band patterns were similar in the treatment of applying chicken manure and organic compound fertilizer of monosodium glutamate (e.g. band No.3 and band No.4). The treatment of chicken manure also has these two bands, but the concentration is low. It showed that both chicken manure and organic compound fertilizer of monosodium glutamate may contain some substance that promotes microbial propagation.

Table 3. Effects of different fertilization on microbial community

Treatment	bacteria (unit/g)	Epiphyte (unit/g)	Actinomyces (unit/g)
CK	5.35×10^6	2.40×10^5	6.60×10^5
Inorganic fertilizer	6.10×10^6	4.00×10^5	5.70×10^5
Pig manure	6.40×10^6	5.95×10^5	1.08×10^6
Cattle manure	5.40×10^6	2.20×10^5	8.15×10^5
Organic compound fertilizer of monosodium glutamate	3.80×10^6	5.95×10^5	8.05×10^5
Chicken manure	2.85×10^7	1.95×10^6	3.95×10^6

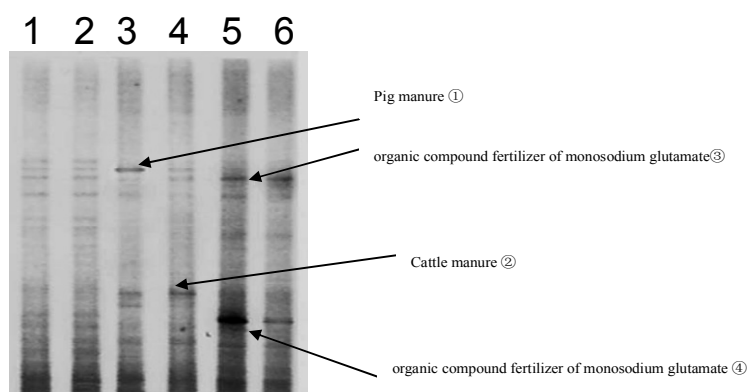


Figure 1. Soil DGGE pattern of different fertilization treatments. M shows λ DNA / HindIII marker, lane 1-6 show: 1 CK; 2 Inorganic fertilizer; 3 Pig manure; 4 Cattle manure; 5 Organic compound fertilizer of monosodium glutamate; 6 Chicken manure.

Conclusions

All fertilizer treatments increased both peanut legume yield and biomass compared no fertilization (CK), with the higher increment in the treatments of monosodium glutamate. Plate count and DGGE analysis have demonstrated that application of organic manure substantially increased soil microbial biomass and microbial community (species) diversity.

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Reference

- Lv WG, Huang QW, Shen QR (2005) The effect of organic fertilizer and organic-inorganic fertilizer application on soil enzymes activities during watermelon growing period. *Journal of Nanjing Agricultural University* **28**, 67-71.
- Ren ZG, Chen YS, Tang FQ (1996) Effect of inorganic fertilizer combined with organic manure on the

- microflora and enzyme activities in paddy soil. *Plant Nutrition and Fertilizer Science* **2**, 279-283.
- Sun RL, Zhao BQ, Zhu LS (2003) Effects of long-term fertilization on soil enzyme activities and its role in adjusting-controlling soil fertility[J]. *Plant Nutrition and Fertilizer Science* **9**, 406-410.
- Cai YF, Liao ZW (2002) Advance in research methods for soil microbial ecology. *Soil and Environment* **11**, 167-171.
- Luo HF, Qi HY, Xue C (2003) A preliminary application of PCR-DGGE to study microbial diversity in soil. *Acta Ecologica Sinica* **23**, 1570-1575.
- Vigdis T, Lisc O (2002) Microbiol diversity and function in soil: from gene to ecosystems. *Current Opinion in Microbiology* **5**, 240-245.
- Zhang SS, Yang XM, Mao ZS (2007) Effects of sterilization on growth of cucumber plants and soil microflora in a continuous mono-cropping soil[J]. *Acta Ecologica Sinica* **27**, 1809-1817.
- Bossio D A, Girvan M S, Verchot L, Bullimore J (2005) Soil microbial community response to land use change in an agricultural landscape of western Kenya. *Microbial Ecology* **49**, 50-62.
- Zhao Y, Zhou ZH, Li W (2005) DNA extraction from soil for molecular microbial community analysis. *Journal of Agro-environmental Science* **24**, 854-860.

Effects of P application method on P utilization in an upland soil: 12-year field micro-plot trials

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Abstract

Data from 12-year field micro-plot trials were analysed to investigate the efficacy of four different phosphorus (P) application methods in a soil-corn system. P was applied annually or once every six years at rates equivalent to 25 or 75 kg P/ha/yr. Grain and stalk yields were little affected by P applications, presumably due to the non limitation of P in the test soil. Nevertheless, P application increased P uptake by plant and Olsen-P in soil. When P was applied less frequently, P uptake and Olsen-P were higher in the first several years but gradually reversed over time. Overall, the 12-year averages in P uptake and Olsen-P were not significantly affected by P application frequency at either P application rate, suggesting that P may be applied at suitable rates once for multiple years in upland soils to lower labor input, although the risk of P loss needs to be carefully considered under field conditions, especially in the first several years.

Key Words

P application rate, P application frequency, P uptake, Olsen-P.

Introduction

P is one of most important nutrient elements limiting agricultural production in most regions of the world. It has a high affinity to soil and, therefore, generally less likely to be lost unless the soil itself erodes away (Eghball *et al.* 1990; Sims *et al.* 1998). Meanwhile P is a vital nonrenewable natural resource. The imbalance in the demand and production of P fertilizer frequently causes its fluctuating prices. To reserve P and save labor input, we carried out a long-term study to the efficacy of various P application methods on P utilization in agroecosystems. Here, we report our results from 12-year field micro-plot trials on P utilization in a soil-corn system treated with fertilizer P at different frequencies and rates.

Methods

Study Site and Experiment Management

A 12-year field experiment was conducted at the Shenyang Experimental Station of Ecology (41°31'N, 123°22'E), Chinese Academy of Sciences, a CERN site in the lower reaches of the Liaohe River Plain in Northeast China from 1997 to 2008. The Station is located in the continental temperate monsoon zone, with dry-cold winter and warm-wet summer. The annual mean temperature is 7.0-8.0°C with a cumulative temperature of 3100~3400°C (not less than 10°C), annual precipitation 650 to 700 mm, and annual non-frost period 147 to 164 days. The soil is an aquic brown soil (silty loam Hapli-Udic Cambisols in Chinese soil taxonomy). The main soil physical and chemical characters are shown in Table 1.

Table 1. Physical and chemical characters of soil.

	Total N g/kg	Total P g/kg	Organic C g/kg	Olsen-P mg/kg	Available K mg/kg	pH
0-20cm	1.01	0.41	10.65	6.99	103.53	7.02
20-40cm	0.83	0.39	7.98	4.76	97.38	7.06

The experiment was installed with six fertilization treatments as follows: T1 (non-fertilization control), T2 (none P application), T3 (annual P application at 25 kg/ha), T4 (once every six years P application at 150 kg/ha, equivalent 25 kg/ha/yr), T5 (annual P application at 75 kg/ha) and T6 (once every six years P application at 450 kg/ha, equivalent 75 kg/ha/yr). Based on the P treatment, the experiment was conducted in two six-year periods (1997-2002 and 2003-2008). Each treatment had triplicates with a completely randomized block design. Each plot (1m×1m) was bordered with concrete walls (depth 1 m) to prevent lateral flow of water and nutrients. The single cropping system was adopted in the study. Four corn seeds (variety Fuyou 1) were planted in each plot in May every year. Triple superphosphate (P content 20%) was broadcasted before soil harrowing. Nitrogen fertilizer as urea was applied annually as top dressing at 150 kg N/ha in all treatments Except T1 at the elongating stage.

Samples Collection and Analysis

Plants were harvested annually in late September and separated into stalk and grain. The samples were dried at 105°C for >72 h and weighted. The samples for P analysis were ground to pass a 1-mm screen. Total P (TP) in plant samples were determined by the molybdenum-ascorbic acid method (Murphy and Riley 1962) after digestion with H₂SO₄ and H₂O₂. Soil samples from 0-20 cm layer were collected annually after harvest using a 3 cm diameter soil auger. All the samples were air-dried and ground to <2 mm prior to P analysis. Olsen-P was determined using the method of Olsen (1954) and the extract P was analyzed colorimetrically using the method of Murphy and Riley (1962). P uptake and Olsen-P from each treatment were normalized against to the no P application treatment (T2) in a specific year for student t test on the 12-year averages in P uptake and Olsen-P among treatments. All other data were subjected to statistical analysis of variance (ANOVA) in the SPSS 13.0 statistical package.

Results

Corn yield

Large annual variations in corn grain and stalk yields were found in each treatment, primarily due to annual climate variations over the twelve years of study (data not shown). N application was found to have a significant effect on the average yields of corn grain and stalk from 1997 to 2008. With N fertilization, the yields were averagely increased by 36% for grain and 22% for stalk (Table 2). Nevertheless, the grain and stalk yields were neither significantly affected by P fertilization rate and frequency among all N fertilization treatments throughout the 12-year experiment (Table 2). This implies that the soil used in this study was limited by N but not likely by P, resulting in little effects of P fertilization on corn grain and stalk yields.

Table 2. Effects of N and P applications on corn grain and stalk yields from 1997 to 2008.

Treatments	N(kg/ha)	P application	Grain (kg/ha)	/T1(%)	Stalk (kg/ha)	/T1(%)
T1	0	0	88833b	100	89867b	100
T2	150	0	121000a	136	110319a	123
T3	150	25 kg/ha per year	120072a	135	110035a	122
T4	150	150 kg/ha per 6 years	120533a	136	108306a	121
T5	150	75 kg/ha per year	122378a	138	109980a	122
T6	150	450 kg/ha/ per 6years	120900a	136	110856a	123

Different letters following the numbers in a column represent a significant difference at $P < 0.05$.

P uptake

The amount of P uptake was increased with the increase of the P application rate during the 12-year experiment (Table 3). The amount of P uptake from the two no P application treatments (T1, T2) were significantly lower than those P fertilization treatments, as reported by Ferguson (2005). The two high P application treatments (T5, T6) had greater amounts of P uptake by grain and stalk than the two low P application treatments (T3, T4). Moreover, the frequency of P application was also found to affect the temporal pattern of P uptake. The once per six years P application treatments (T4, T6) had greater P uptake by grain and stalk than their corresponding annual P application treatments (T3, T5) in the first several years of each period (Figures 1, 2), and gradually reversed thereafter. The t test showed that the 12-year averages of P uptake by grain and stalk were not significantly affected by application frequency at either of the two P application rates. Due to the insignificant differences in yields between P application treatments in all years (Table 2), such difference in temporal pattern of P uptake between P treatments was ascribed to the luxury uptake of P.

Table 3. Effects of N and P applications on P uptake from 1997 to 2008.

Treatments	P uptake (kg/ha)		
	Grain	Stalk	Sum
T1	275.35e	110.02c	385.37c
T2	344.97d	130.31bc	475.28b
T3	373.38cd	145.68ab	519.06b
T4	380.68bc	134.84abc	523.10b
T5	419.49a	158.54ab	586.53a
T6	411.54ab	170.80a	582.33a

Different letters following the numbers in a column represent a significant difference at $P < 0.05$.

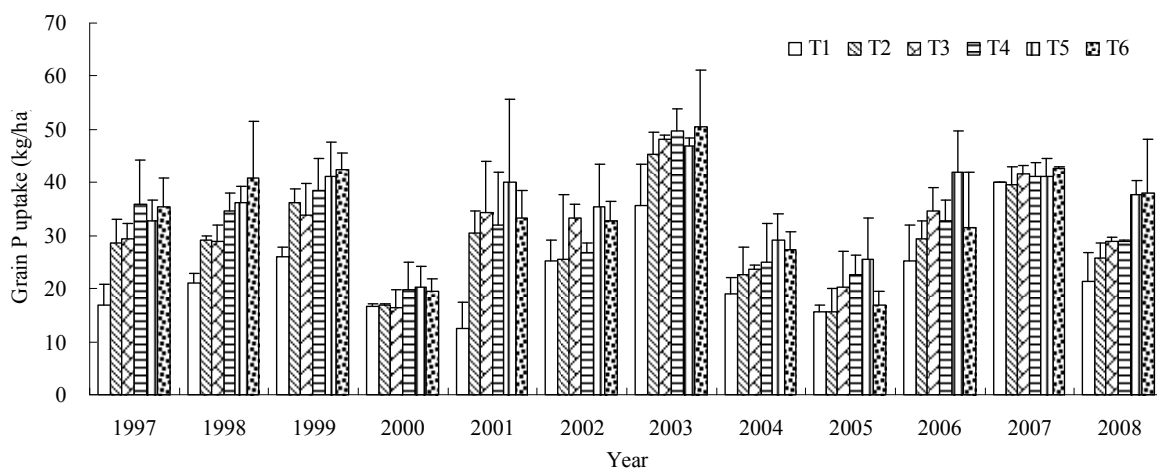


Figure 1. Grain P uptake as influenced by P and N treatments.

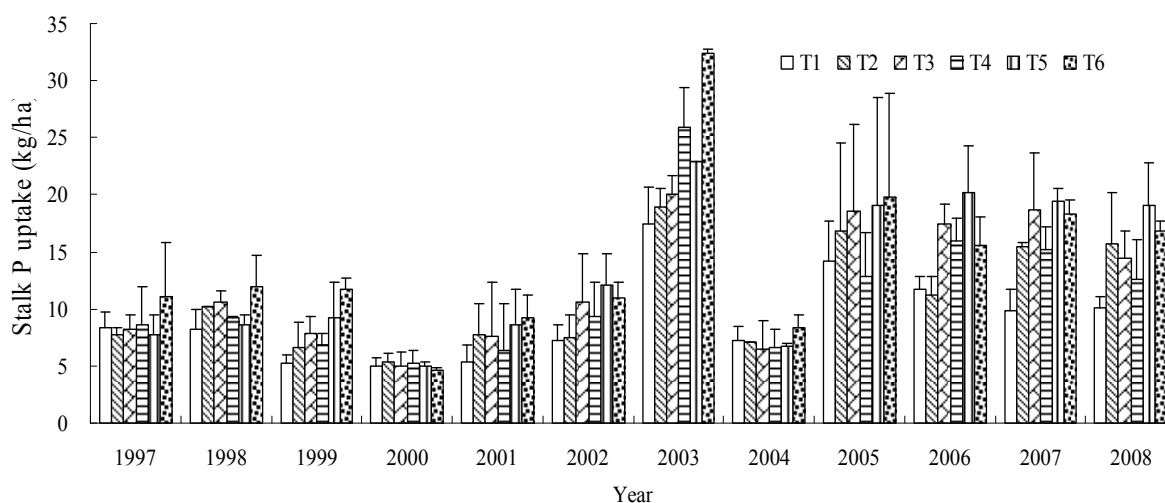


Figure 2. Stalk P uptake as influenced by N and P treatments.

Soil test P (Olsen-P)

Variations in soil Olsen-P from these treatments followed a similar pattern in the two periods (1997-2002, 2003-2008) (Figure 3). Here, we mainly focused our discussion on the first period (1997 to 2002). Olsen-P in surface soil was not much changed in the no P fertilization treatments (T1 and T2) over the first 6-yr period even P being respectively removed at 385.37 and 475.28 kg P/ha with corn. Similar results have been reported by Rehm (1984) and Zhang (2004). Olsen-P was maintained through mineralization of soil organic P, desorption and dissolution of native soil inorganic P. So, it was closely related to soil type and the initial soil P status, which is affected by the previous fertilization and cropping history (Dodd *et al.* 2005). As such, no P fertilization for long years may cause a decrease in Olsen-P in some soils (Webb *et al.* 1992; Randall *et al.* 1997), but may not in some other soils as mentioned above.

Both the rate and frequency of P application affected the residual effect of fertilizer P. Soil Olsen-P tended to gradually increase over time in the annual application treatments (T3 and T5), and increased with the increase of P application rate. For example, Soil Olsen-P from treatments T3 and T5 were increased at 2.22 mg/kg/yr and 4.90 mg/kg/yr, respectively. The annual P application treatments (T3, T5) had less Olsen-P than the once every six years P application treatments (T4, T6) in the first several years, but gradually reversed over time. However, the 12-year average of Olsen-P was not significantly affected by application frequency ($p=0.28$ at the low P application rate, $p=0.09$ at the high rate). The turning time was delayed with increased P application, occurring at the 5th year for the high P application treatments (T5, T6) while at the 4th year for the low P application treatments (T3, T4).

In contrast, the Olsen-P contents in the once per six-year P application treatments (T4 and T6) increased to their maximums in the 1st year after P application but decreased after the 2nd year. The decrease rate of Olsen-P in treatment T4 was small (5.84 mg/kg/yr) at the beginning and stably maintained at 12 mg/kg after 2000. Olsen-P content in treatment T6 decreased at 10.76 mg/kg/yr after the first year.

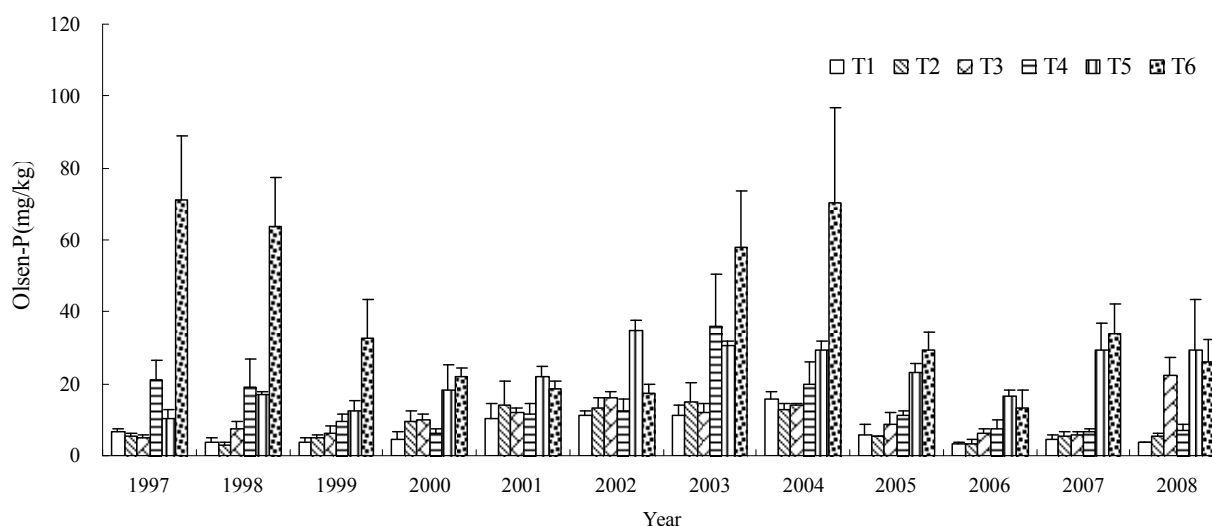


Figure 3. Olsen-P in the topsoil (0-20cm) as affected by N and P treatments.

Conclusion

Although P fertilization had little effect on corn grain and stalk yields in the 12-year experiment, P uptake and Olsen-P were increased with an increase in P application. When P was applied once every six years instead of annually, P uptake and Olsen-P were higher in the first years of each 6-year period but gradually reversed over time. Olsen-P tended to gradually increase over time when P was applied annually but reached a maximum at the 1st year and decreased after the 2nd year when applied once every six years. The average amounts of Olsen-P and P uptake from the low P application treatments in the 12-year experiment was not significantly affected by P application frequency, suggesting that P may be applied once at suitable rates for multiple years in upland soils to lower labor input, although the risk of P loss from P application needs to be carefully considered under field conditions, especially in the first several years.

Acknowledgements

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References

- Murphy J, Riley JP (1962) A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* **27**, 31-36.
- Olsen SR, Cole CV, Watanabe FS (1954) 'Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate'. (US Gov Print Office: Washington DC).
- Eghball B, Sander DH, Skopp J (1990) Diffusion, adsorption, and predicted longevity of banded phosphorus-fertilizer in three soils. *Soil Sci Soc Am J* **54**, 1161-1165.
- Sims JT, Simard RR, Joern BC (1998) Phosphorus loss in agricultural drainage: Historical perspective and current research. *J Environ Qual* **27**, 277-293.
- Zhang TQ, MacKenzie AF, Liang BC (1994) Soil test phosphorus and phosphorus fractions with long-term phosphorus addition and depletion. *Soil Sci Soc Am J* **68**, 519-528.
- Rehm GW, Sorensen RC, Wiese RA (1984) Soil test values for phosphorus, potassium and zinc as affected by rate applied to corn. *Soil Sci Soc Am J* **48**, 814-818.
- Webb JR, Mallarino AP, Blackmer AM (1992) Effects of Residual and Annually applied phosphorus on soil test values and yields of corn and soybean. *J Prod Agric* **5**, 148-152.
- Randall GW, Iragavarapu TK, Evans SD (1997) Long-term P and K applications. I. Effect on soil test incline and decline rates and critical soil test levels. *J Prod Agric* **10**, 565-571.
- Dodd JR, Mallarino AP (2005) Soil-test phosphorus and crop grain yield responses to long-term phosphorus fertilization for corn-soybean rotations. *Soil Sci Soc Am J* **69**, 1118-1128.
- Ferguson RB, Nienaber JA, Eigenberg RA (2005) Long-term effects of sustained beef feedlot manure application on soil nutrients, corn silage yield, and nutrient uptake. *J Environ Qual* **34**, 1672-1681.

Effects of rotation and fertilization on Chernozem soils of Moldova

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Abstract

The dominant concept of technologic intensification of agriculture since the era of “green revolution” led to many negative consequences in economic, ecologic, energetic and social aspects. The results obtained in long-term experiments with different crop rotations and permanent crops at the Research Center “Selectia” Republic of Moldova have proved a high “effect of rotation” and the irreplaceable role of soil fertility on yield formation for the majority of crops. The importance of soil fertility on yield formation remains very high even for new varieties (hybrids) of crops and using optimal rates of mineral fertilizers and pesticides for weed, pest and disease control. Sustainable development of agriculture needs urgent structural changes in the existing farming systems on arable soils which in order to balance the processes of mineralization and humification of soil organic matter.

Key Words

Crop rotation, fertilization, soil fertility, soil organic matter.

Introduction

The technologic intensification of agriculture with increased rates of mineral fertilizers, new varieties (hybrids) of crops, new pesticides for weed, pest and disease control etc. led to the underestimation of crop rotations and organic fertilization, which are irreplaceable for restoring soil fertility. In other words, the main attention during technological intensification of agriculture was focused on increasing crop productivity without attention to soil fertility. Because of the non-observance of the principal laws of arable agriculture (crop rotation and returning energy, not only as NPK) agriculture is running into many ecological, energetical, economical and social problems, which do not allow achieve of sustainable development (Karlen *et al.* 1994; Lal 2001);. Agriculture needs both technological and structural changes in order to prevent the above mentioned problems (Herbert and Koepf 1992; Frederick and Kirschenman 2007). By respecting crop rotations, by integration of plant and animal husbandries, by ecological landscape management, etc. it would be possible to balance the mineralization and humification of soil organic matter as one of the most important particularities of arable farming.

Methods and results

Research have been conducted in long-term experiments with different crop rotations and permanent crops founded in 1962 in the northern part of Moldova (Balti steppe) on Chernozem soils. More details regarding methods and conditions of researches were described in our previous publications (Boincean 1999; Boincean 2009). Here we are presenting the results obtained during the last 15 years for both crop rotations and permanent crops, both on fertilized and unfertilized plots.

“The effect of rotation” means the difference between yields of crops in crop rotation and in permanent cropping expressed as percentages. The results obtained in our long-term experiments prove the importance of crop rotation even on fertilized plots, especially for winter wheat, sugar beets and sunflower (Table 1). All crops are receptive to crop rotation on unfertilized plots. It was supposed during the era of green revolution that chemicals (fertilizers, pesticides, new-more resistant crop varieties (hybrids)) would replace the agronomic significance of crop rotation. It was not the case. The effect of rotation remains very high even on fertilized plots. The other assumption during the era of total chemization of agriculture was that mineral fertilizers would certainly increase the level of yields, especially for the new varieties (hybrids) of crops. Data from Table 2 and 3 indicate on share of fertilization on yield formation for different crops in crop rotations with 10 and 7 fields and in permanent cropping. The higher the diversity of crops in crop rotation (10 fields comparatively with 7 fields crop rotations) the lower is the contribution of fertilization (organo-mineral fertilizers) to yield formation. The most receptive to fertilization are winter wheat, sugar beets and winter barley in both 10 and 7 fields crop rotations. For winter wheat we have determined the share of new varieties regularly registered in Moldova in yield formation comparatively with the variety Odesa 51, which was grown simultaneously in crop rotations after different predecessors and in permanent crop.

Table 1. Effect of rotation in the long-term experiment of the Research Center Selectia, Republic of Moldova, average for 1994-2008.

Crops	Unfertilized				Fertilized			
	Crop rotation	Permanent crop	±, t/ha	Effect of rotation,	Crop rotation	Permanent crop	±, t/ha	Effect of rotation,
	(-----t/ha-----)			%	(-----t/ha-----)			%
Winter wheat	4,74	2,10	+2,64	125,7	5,10	2,99	+2,11	70,6
Sugar beets	34,07	9,56	+24,51	256,4	43,56	19,32	+24,24	125,5
Corn for grain	4,97	3,67	+1,3	35,4	5,36	5,13	+0,23	4,3
Winter barley	3,23	2,02	+1,21	59,9	3,93	3,69	+0,24	6,5
Sunflower	2,05	1,41	+0,64	45,4	2,16	1,51	+0,65	43,0

Table 2. Yields of different crops in 10 and 7 fields crop rotations on fertilized and unfertilized plots, Research Center “Selectia”, average for 1994-2008, t/ha.

Crops	Crop rotations															
	10 field crop rotation										7 field crop rotation					
	Unfertilized			Fertilized			± from fertilizers				Share in the yield of		Un-ferti- lized	Fer-tili- zed	± from ferti- lizers	Share of fertil.+ varie-ties
	Odesa 51	New varie-ties	±	Odesa 51	New varie-ties	±	Odesa 51	New variet	Varie- ties	Varie-ties+ fertil.						
Winter wheat (after vetch and oats for green mass)	4,18	4,74	+0,56	4,58	5,10	+0,52	+0,40	+0,36	13,4	22,0	3,98	A4,28	+0,30	7,5		
Sugar beets		34,07			43,56			+9,49		27,8	24,76	38,95	+14,19	57,3		
Corn for grain		4,97			5,36			+0,39		7,8	4,99	5,47	+0,48	9,6		
Winter barley		3,23			3,93			+0,70		21,7	2,52	3,42	+0,90	35,7		
Sunflower		2,05			2,16			+0,11		5,4	1,41	1,75	+0,34	24,1		

^Alodging**Table 3. Yields of permanent crops in the long-term experiment of the Research Center “Selectia”, (Republic of Moldova) average for 1994-2008, t/ha.**

Crops	Permanent crops									
	Unfertilized			Fertilized			± from fertilizers			Share in the yield of
	Odesa 51	New varieties	±	Odesa 51	New varieties	±	Odesa 51	New varieties	varieties	varieties+ fertilizers
Inter wheat after vetch and oats for green mass	1,93	2,10	+0,18	2,94	2,99	+0,05	+1,01	+0,88	9,3%	54,9
Sugar beets		9,56			19,32			+9,76		102,1
Corn for grain		3,67			5,13			+14,6		39,8
Winter barley		2,02			3,69			+1,67		82,7
Sunflower		1,41			1,51			+0,10		7,1

The share of new varieties in yield formation of winter wheat is only 13,4% in 10 fields crop rotations and 9,3% in permanent cropping. New varieties of winter wheat react higher to the level of soil fertility than to increased rates of fertilizers. The share of fertilization in yield formation is significantly higher in permanent crop comparatively with both 10 and 7 fields crop rotations. The share of fertilization (together with the new varieties of winter wheat) in yield formation for different crops in crop rotation and permanent crop consists, accordingly:

Winter wheat – 7,5-22,0 and 54,9%
 Sugar beets – 27,8-57,3 and 102,1%
 Corn for grain – 7,8-9,6 and 39,8%
 Winter barley – 21,7-35,7 and 82,7%
 Sunflower – 5,4-24,1 and 7,1%

Therefore, the better is the crop rotation the lower is the share of fertilization in yield formation and vice versa. In other words, we have to compensate the lack of crop rotation by higher rates of mineral fertilizers and pesticides. This is problematic from economic and ecological points of view like also for people's and animal's health. The share of soil fertility in yield formation for different crops varieties in crop rotation and permanent cropping consists, accordingly:

Winter wheat – 92,5-78,0 and 45,1%
 Sugar beets – 72,2-42,7 and 0%
 Corn for grain – 92,2-90,4 and 60,2%
 Winter barley – 78,3-64,3 and 17,3%
 Sunflower – 94,6-75,9 and 92,9%

It is evident the predominance of soil fertility in yield formation in crop rotation. Data from our long-term experiments proves also the same level of yield for different crops under the influence of organic and organo-mineral fertilization, but organic fertilizers have indisputable advantages in restoring the stocks of soil organic matter in arable cernoziom soils.

Conclusions

1. "The effect of rotation" remain high enough even by extending new varieties of crops on fertilized plots.
2. The share of new varieties of winter wheat in yield formation is higher in crop rotation than in permanent crop and consists only 13,4 and 9,3%, accordingly. New varieties of winter wheat react more to the level of soil fertility than to the fertilization of crop.
3. The higher is the diversity of crops in crop rotation the lower is the share of fertilization in yield formation.
4. The share of fertilization in yield formation is significantly higher in permanent crop relatively to crop rotation for majority of crops. Accordingly, the share of soil fertility in yield formation is higher in crop rotation and lower in permanent crop. By respecting crop rotations it is possible to cut the dependence of farms from chemicals and to prevent simultaneously the pollution and degradation of the environment.
5. Agriculture needs both technologic and, especially, structural changes in order to increase the diversity of crops in crop rotations and integration of animal and crop husbandries for more efficient restoration of soil fertility.

References

- Herbert H., Koepf (1992) 'Soil fertility in sustainable low input farming'. (Michael Fields Agricultural Institute, Bulletin N3)
- Karlen DL, Varvel GE, Bullock DG, Cruse RM (1994) Crop rotations for the 21 st century. *Advance in Agronomy* **53**, 1-45.
- Lal R (2001) Managing world soils for food security and environmental quality. *Advances in Agronomy*. **74**, 155-186.
- Frederick L, Kirschenman (2007) Potential for a new generation of biodiversity in agroecosystems of the future. *Agronomy Journal*, **99**, 373-376.
- Boincean BP (1999) 'Ecological agriculture in the Republic of Moldova (crop rotation and soil organic matter)'. (Chisinau: Stiinta).
- Boincean BP (2009) 'The role of ecological chemistry in pollution research and sustainable development'. (Springer Science: Business media).

Estimating N contribution from organic fertilizers and cover crop residues using online calculators

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Abstract

Satisfying crop nitrogen (N) requirements efficiently requires accounting for plant-available N (PAN) release from organic inputs. Relatively simple PAN regression models based on total N concentration of organic inputs have been developed (Organic Fertilizer Calculator) or are in development (Cover Crop Calculator). The Calculators are distributed to agricultural professionals and farmers via Web download as a spreadsheet with accompanying instructions/examples. Regression equations implemented in the Calculators are similar or identical to those reported in world literature; they have been verified by aerobic incubations in the laboratory and by N fertilizer equivalency trials in the field. The Calculators predict PAN for 28 d and 70 d after spring or early summer incorporation of organic material, assuming typical field conditions for our summer irrigated vegetable crops (moist soil; 20 to 25°C). Because most fresh organic amendments and cover crop residues decompose rapidly, PAN release is also rapid. For a given organic material, PAN was consistent across several soil textures. Calculator predictions can be verified in the field by soil sampling early in the growing season, prior to significant crop N uptake and opportunity for PAN loss. We welcome collaborators wanting to verify PAN Calculator predictions in diverse environments.

Key Words

Nutrient management, nitrogen, organic fertilizer, cover crops.

Introduction

Adoption of national rules for Certified Organic food production in the USA in 2002 has stimulated greater interest in organic farming and meeting crop N needs using manures, cover crops and other organic materials. Typical guidance for manure use in organic crop production (Kuepper 2003) provides only typical total nitrogen analyses for manures with no estimate of PAN. Many correlations between N analyses of organic materials and the amount and timing of available N release have been reported for animal manures, crop residues, and other organic materials (Vigil and Kissel 1991; Trinsoutrot *et al.* 2000). This paper provides a brief summary of our efforts to provide farmers and agricultural professionals in the maritime Pacific Northwest USA with improved estimates of PAN provided by organic inputs, using Web-based Calculators. The Calculators combine PAN estimates with economic analysis (not discussed here).

Methods

Both Calculators require users to specify application rate, dry matter content, and total N analysis of fertilizer or cover crop. The Calculators assume that for fresh organic materials, C concentration is relatively constant (near 40%), so that total N concentration is a useful indicator of C:N ratio.

Organic Fertilizer Calculator

This Calculator utilizes linear regression equations with two time steps (28 and 70d; Figure 1). The time steps are equivalent to approx. 600 and 1500 degree days (0 °C base temperature) after soil incorporation:

Prediction equation for PAN at 28 d after soil incorporation (600 degree days) (1)

For fertilizer total N < 6% dry wt. basis, %PAN = -30 + 15 (fertilizer total N%)

For fertilizer total N ≥ 6% dry wt. basis, %PAN = 60%

Prediction equation for PAN at 70 d after soil incorporation (1500 degree days) (2)

%PAN = 28d PAN + 15%

Cover crop calculator

This Calculator (in development, Sullivan and Andrews) uses a published regression equation (Vigil and Kissel 1991) for estimating PAN at 70 d (1500 degree days) after soil incorporation:

PAN (% of cover crop total N) = -53.44 + 16.98 (cover crop %N x 10)^{1/2} (3)

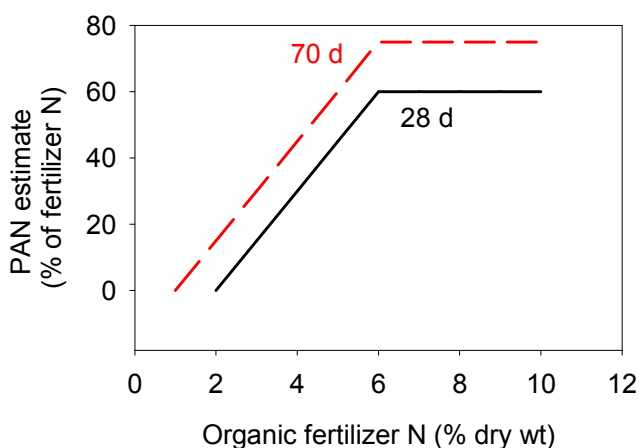


Figure 1. Plant-available N estimates given as Extension guidance in OSU Organic Fertilizer Calculator (Eq. 1 and 2; Andrews and Foster 2007) for approximately 28d and 70d following a late spring incorporation of organic fertilizer. Expressed as degree days with 0 °C base temperature, the 28d prediction is for approximately 600 degree days, and the 70d prediction is for 1500 degree days after organic fertilizer incorporation.

Results

Organic fertilizer calculator

This Calculator arose as a byproduct of a larger project that evaluated simulation modelling to predict N availability (Gale *et al.* 2006). Growers and grower advisors wanted a tool that was simpler to use than a simulation model and allowed economic comparison of fertilizers. We decided to look at our existing data with a grower-friendly Calculator in mind. We found reasonable linear correlation between organic fertilizer total N% (dry weight basis) and PAN measured in field trials (Figure 2) and in laboratory incubations. We found similar PAN for the same organic material applied to a sandy loam and a silt loam soil. PAN from stable composts in the Gale *et al.* (2006) dataset was not related to compost total N percentage, so the equation given in the Organic Fertilizer Calculator is to be used only for fresh organic materials. We found that dry-stacked poultry litter (sold as “compost”) had decomposition in soil and %PAN similar to fresh organic materials (Gale *et al.* 2006).

Limitations to the Calculator are described in the Extension publication (Andrews and Foster 2007). The Calculator does not account for ammonia that may be lost at application. It also assumes that PAN is not lost via leaching or denitrification. Under our summer Mediterranean climate with crops grown under sprinkler irrigation, the assumption of insignificant PAN loss under good management has been supported by field PAN being equivalent to lab incubation PAN in our field trials (Gale *et al.* 2006). We lacked data on higher N analysis specialty products available for use in USDA Certified Organic production. To gain additional data on high N specialty products, we performed a 28-d laboratory incubation using fertilizers offered for sale to organic farmers in Portland, Oregon including: seed meals, fish byproducts, and animal byproducts (Table 1). Most of the specialty products decomposed rapidly. Most specialty products with greater than 6% total N released 60+% PAN in 28 d. Decomposition (%) for specialty products with 6+% total N was similar to PAN (%). Plant-available N (%) was similar for most fertilizers with total N percentage > 6%. Experimental data for PAN release from high N concentration organic fertilizers (>6% total N) typically ranged from 60 to near 100% (Figure 2 and unpublished data). Therefore, the Calculator estimate of 75% PAN for 70 d after application is on the conservative side.

Cover crop calculator

We have conducted laboratory incubations and field trials, and to date, our data appears to be a reasonable fit with a published equation (Vigil and Kissel 1991) for laboratory incubations at 70-d (Figure 3) and for post-application field soil nitrate-N (Figure 4). In the lab incubation (Figure 3), PAN increased substantially for cover crop residues having < 2.5% total N between 28 d and 70 d. We are collecting additional data in lab and field that will determine what equation should be used to estimate cover crop PAN at 28 d.

Table 1. Decomposition and PAN from organic specialty products in a 28-d aerobic incubation in Chehalis silt loam soil at 22 °C, 25% gravimetric water content.

Fertilizer N source ^A	Fertilizer		PAN	Decomposition	
	Total N	C:N	28 d	7 d	28 d
	%		% of fertilizer N	% of fertilizer N	% of fertilizer C
seaweed extract	1	29	0	21	38
kelp meal	1	26	-6	8	14
alfalfa meal	2	17	4	32	48
ground fish bone	5	3	33	20	33
meat and bone meal	8	5	44	41	53
soybean meal	8	5	68	49	69
fish/feather/alfalfa meal	8	5	58	43	59
bone meal	9	5	58	49	59
feather meal, bone meal	9	4	63	27	54
fish meal	9	4	62	50	65
corn gluten meal	10	5	72	49	69
granulated feather meal	11	4	65	31	55
fish protein digest	12	4	64	52	61
feather meal	13	4	63	41	59
blood meal	14	4	63	39	57

^AMost organic fertilizer products contained additional salts supplying other nutrients (blended fertilizers). Fertilizers incorporated at 300 mg total N /kg soil in incubation.

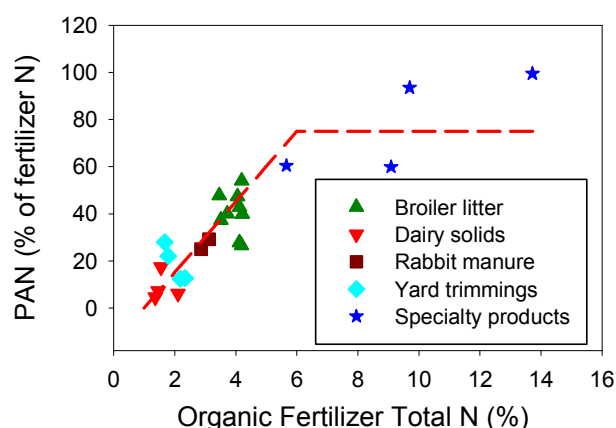


Figure 2. Plant-available N determined in N fertilizer equivalency field trials over 4 site-years with sweet corn vs. total N concentration of preplant-applied organic fertilizers (Gale *et al.* 2006). Dotted line is the regression equation chosen for implementation as 70-d predicted PAN in Extension guidance (Eq.2; OSU Organic Fertilizer Calculator; Andrews and Foster 2007).

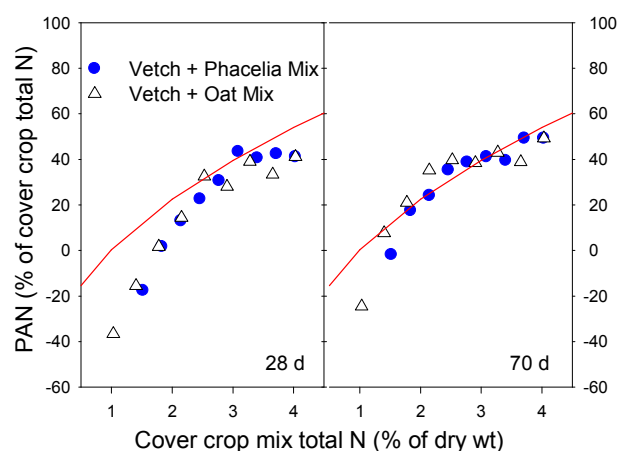


Figure 3. Plant-available N after 28d (left) and 70d (right) following addition of mixtures of cover crop residues to Chehalis silt loam soil (Garrett 2009) vs. predicted PAN (solid line; Vigil and Kissel 1991; Eq. 3). Aerobic laboratory incubation (22°C, 25% gravimetric moisture). Unmixed cover crop total N concentrations were 4.0% for vetch, 1.0% for oat, and 1.5% for phacelia. Cover crop residues incorporated at constant rate (5g /kg soil), with proportions of vetch at 0, 12, 25, 37, 50, 62, 75, 87 and 100%.

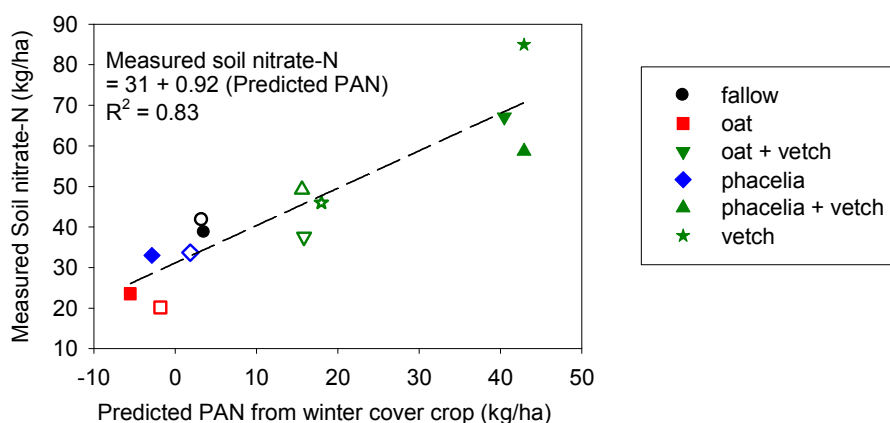


Figure 4. Predicted PAN (Vigil and Kissel 1991; Eq. 3) from cover crop residues vs. soil nitrate-N (0-30 cm depth; Garrett 2009) measured in mid-July (approximately 65 d after winter cover crop incorporation). Soil samples collected between rows where crop (broccoli) roots were absent. Filled symbols = 2007, open symbols = 2008 data.

Conclusion

The Organic Fertilizer Calculator is now available (Andrews and Foster 2007), and the Cover Crop Calculator will soon be available for download from the OSU Extension website. Calculator predictions can be verified in the field by soil sampling early in the growing season, prior to significant crop N uptake and opportunity for PAN loss. We welcome collaborators wanting to verify the applicability of the PAN Calculators in diverse environments.

Acknowledgements

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References

- Andrews N, Foster J (2007) 'Organic Fertilizer Calculator: A Planning Tool for Comparing the Cost, Value and Nitrogen Availability of Organic Materials'. (EM 8936-E. OSU Extension Service: Corvallis). <http://smallfarms.oregonstate.edu/organic-fertilizer-calculator>
- Garrett A (2009) Improving nitrogen management with cover crops in organic broccoli production. MS thesis, Oregon State University, Corvallis.
- Gale ES, Sullivan DM, Hemphill D, Cogger CG, Bary AI, Myhre EA (2006) Estimating Plant-Available Nitrogen Release from Manures, Composts, and Specialty Products. *J. Environ. Qual.* **35**, 2321-2332.
- Kuepper G (2003) 'Manures for organic crop production. Appropriate Technology Transfer for Rural Areas (ATTRA)'. (Fayetteville: AR). <http://attra.ncat.org/attra-pub/PDF/manures.pdf>
- Trinsoutrot I, Recous R, Bentz B, Lineres M, Cheneby D, Nicolardot B (2000) Biochemical quality of crop residues and carbon and nitrogen mineralization kinetics under nonlimiting nitrogen conditions. *Soil Sci. Soc. Am. J.* **64**, 918-926.
- Vigil MF, Kissel DE (1991) Equations for estimating the amount of nitrogen mineralized from crop residues. *Soil Sci. Soc. Am. J.* **55**, 757-761.

Evaluation of Rice Genotypes for Zinc Efficiency under Acidic Flooded Condition

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Abstract

Zinc deficiency in the rice plant has been identified as the major cause of low yield. Flooding and submergence bring about a decline in available zinc due to pH changes and the formation of insoluble zinc compounds. A field experiment was conducted to evaluate the rice genotypes for zinc use efficiency. Six rice (*Oryza sativa* L) genotypes were tested at two (0 and 15 Kg/ha) levels of zinc. Genotypes differed significantly in grain yield and its components. Based on the grain yield efficiency index, genotypes were classified as efficient, medium efficient and most inefficient. The most zinc efficient genotype was: MR 106 and medium efficient were Seri Malaysia Dua, MR 220 and MR 219. The most inefficient genotypes were MR211 and Bahagia. Grain yield efficiency is the best tool to categorize the genotypes into efficient and inefficient groups.

Key Words

Rice genotypes, zinc efficiency, acidic flooded condition.

Introduction

Zinc deficiency is a widespread micronutrient deficiency and is one of the major constraints in world food production. It is therefore, essential to identify the zinc-deficient areas, and the different causes of deficiency. The submerged soils are well recognized for less zinc availability to the plants due reaction of zinc with free sulphide (Mikkelsen and Shiou 1977). Flooding and submergence bring about a decline in available zinc due to pH changes and the formation of insoluble zinc compounds. The soil pH rises with the onset of reducing (gleying) conditions and zinc solubility declines 100 times for each unit increase in pH (Lindsay 1972). The insoluble zinc compounds formed are likely to be with Mn and Fe hydroxides from the breakdown of oxides and adsorption on carbonate especially magnesium carbonate. Under the submerged conditions of rice cultivation, zinc (either native or applied) is changed into amorphous sesquioxide precipitates or franklinite; $ZnFe_2O_4$ (Sajwan and Lindsay 1988). Kedah and Kalantan states are the main paddy growing areas of Malaysia. The soils of Kalantan are low in zinc (Hafeez *et al.* 2009) and soil of Kedah is low in boron (Saleem *et al.* 2009). Due to inadequate information available on the subject, cultivation of crops highly susceptible to zinc deficiency may aggravate the situation by adversely affecting the yield as well as human health. Research efforts are therefore, required to screen the rice genotypes on a zinc efficient and zinc inefficient basis, and develop the methods for improving zinc efficiency in rice (Lindsay *et al.* 2000). Furthermore, no information is available on the zinc efficiency of Malaysian rice genotypes. Therefore this work was undertaken to screen the rice genotypes for zinc efficiency.

Materials and Methods

The genotypes included in this study were; Seri Malaysia Dua, MR 106, MR 219 and MR 220, MR 211 and Bahagia. The experiment was designed as randomized complete block with three replications. The field experiment was conducted on the Lankong (Typic Pelludert) soil series to compare the performance of six genotypes selected under the two levels of zinc (0 (Zn_0) and 5 (Zn_{15}) kg/ha). It had the following chemical and textural properties: EC 1353 $\mu S/cm$, pH 4.89(1:2.5 soil water ratio), Extractable P 2.20 mg/kg (Bray and Kurtz #2 extractants (Bray Kurtz, 1945), Organic carbon 20 g/kg of soil (Carbon analyzer), Cu 1.22 mg/kg, Fe 122 mg kg^{-1} , Mn 6 mg/kg and Zn 0.21 mg/kg (double acid method by using Atomic Absorption Lindsay and Cox (1985) the soil was silty clay in texture (Gee and Bauder 1986). The area of each plot was 12 m^2 . All the plots received N at 140 kg/ha and P at 90 kg P_2O_5/ha . The grain yield efficiency index was calculated by formula (Graham 1984).

The accuracy of zinc analyses of the plant tissue was checked by comparing with certified zinc standard samples obtained from National Institute of Standards and Technology Standards Reference Materials, Gaithersburg, USA.

Results

The results indicate that there is significant effect of zinc levels on yield parameters of tropical rice genotypes. While genotypes has also significant effect on all the parameters except plant height, number of tillers and shoot dry weight. The zinc x genotype interaction was non-significant for all parameters studied (Table 1).

Table 1. The significance of F values derived from analysis of variance on the effect of zinc, genotypes and zinc x genotype interaction on plant characteristics and yield parameters.

Variables	Zinc levels	Genotypes	Zinc x G	CV (%)
Plant height	NS	NS	NS	11.69
Number of tillers	S	S	NS	8.5
Number of grains/panicle	S	S	NS	23.26
Panicle numbers per 10 plants	S	S	NS	12.17
Grain yield	S	S	NS	11.06
Shoot dry weight	S	S	S	14.23
1000 grain weight	S	S	NS	9.26

The number of grains per panicle is an important yield component of rice; it contributes towards the yield capacity of a crop. The zinc level had significant effect on the number of grains per panicle (Table 2), the maximum (116.55) number of grains per panicle was found in MR 106 genotype and minimum (70.78) was in Seri Malaysia Dua genotype. Panicle numbers per ten plants ranged from 10.10 to 16.06 among the six genotypes. Genotype MR 106 had highest (16.06) panicle number as compared with the other genotypes. Similarly, genotype Seri Malaysia Dua had the lowest (10.10) panicle number per ten plants as compared with other rice genotypes. The increase in grains per panicle with the application of zinc was attributed to adequate supply of zinc that might have increase the availability and uptake of other essential nutrients resulting in improvement in metabolic activities (Sharma *et al.* 1990). Pandey *et al.* (2001) reported that the floral development of zinc deficient plants is also severely affected due to low enzymatic activity.

The results on the grain yield of six rice genotypes as influenced by the application of zinc are presented in Table 2. The grain yield was significantly affected by zinc application. Grain yield variation was significant among genotypes and varied from 2.15 to 7.05 tons ha⁻¹. Maximum grain yield (7.05 tons ha⁻¹) was produced by Bahagia rice genotype which is a 47% increase as compared to the control. MR 211 genotype produced the significantly lowest (2.15 ton ha⁻¹) grain yield as compared with the other six rice genotypes. The results indicate that zinc application increased the yield of all six genotypes as compare with no application which might be due to the effect of zinc on the proliferation of roots so the uptake rate from soil was increased and supplying it the aerial parts of the plant. Rehman *et al.* (2001) reported similar results. Pandey *et al.* (1995, 2001, and 2005) were also of the view that poor grains could be produced in zinc deficient plants.

Table 2. Yield and yield components of 6 tropical rice genotypes affected by two levels of zinc.

Genotypes	Number grains/panicle	Grain yield (ton/ha)	Shoot dry weight kg/m ²	Grain yield efficiency index 0.74-0.81 range
Seri Malaysia Dua	86ab	5.52b	1.71a	0.90b
MR 106	116.55a	6.94a	1.44ab	1.50a
MR 219	93.65ab	6.83a	1.51ab	1.39a
MR220	99.20ab	5.86b	1.24b	1.91ab
MR 211	73.72b	4.15c	1.25b	0.69c
Bahagia	119.62a	7.05a	1.66a	0.45c

Statistical analysis showed that the effect of zinc on various rice genotypes on shoot dry weight was significant at the 5% level of probability. Shoot dry weight varied from 1.24 to 1.71 Kg m². On average for all genotypes shoot dry weight was 1.46 kg/m². The highest dry matter yield 1.71 kg/m² was observed for Seri Malaysia Dua and lowest 1.24 Kg 1 m² was for MR 220 rice genotype. Dry matter significantly increased with the application of zinc fertilizer and might be due to the development of longer and thin plants (Graham and Rengel 1993) or may due to plant absorbing more zinc and translocating it to shoots for dry matter production. Similar results were observed by Yaseen *et al.* (2000).

Grain yield efficiency is the best tool to categorize the genotypes into efficient and inefficient groups. Genotype having a grain efficiency more than 0.81 are considered as most efficient and those lower than 0.71 are considered as most inefficient genotypes, whereas, the genotypes in between these two limits are considered medium in zinc-use efficiency. According to this criterion, the most zinc efficient genotype was: MR 106 and medium efficient were Seri Malaysia Dua, MR 220 and MR 219. The most inefficient genotypes were MR211 and Bahagia.

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References

- Graham RD, Raengel Z (1993) Genotypic variation in zinc uptake and utilization by plants. In 'zinc in soils and plants' (Ed D Robson) pp. 107 - 114. (Kluwer Academic Publishers: Netherlands).
- Hacisalihoglu G, Hart JJ, Kochian LV (2002) High and low- efficiency zinc transport systems and their possible role in zinc efficiency in bread wheat. *Plant Physiology* **125**, 456-463.
- Hacisalihoglu G, Hart JJ, Wang Y, Cakmak I, Kochian LB (2003a) Zinc efficiency is correlated with enhanced expression and activity of Cu/Zinc superoxide dismutase and carbonic anhydrase in wheat. *Plant physiology* **131**, 595-602.
- Hafeez, B, Khanif YM, Samsuri AW, Radziah O, Saleem M (2009). Zinc status of Kelantan state. In 'Proceeding of Soils 2009 on Soil health: Preserving resources for sustainable Agriculture from 13-15 April, 2009 at Terengganu'. pp.290-293. (Malaysian Society of Soil Science).
- Lindsay W. (1972) Zinc in soil and plant nutrition. *Adv. Agron.* **24**, 147-188
- Lindsay (2000) Zinc: The Next Global Agenda. *Mal J Nutr* **6**, 189-195.
- Mikkelsen DS, Shiou K (1977) Zinc fertilisation and behaviour in flooded soils. Spec. Publ. No. 5 Comm. Agric. Bur., Farnham Royal.
- Pandey N, Gupta M, Sharma CP (2001) Zinc efficiency affects pollen structure and viability in green gram (*Vigna radiate* L. cv T-44). *Geophytology* **28**, 31-34.
- Pandey (2005) Plant micronutrients and their stress response. In 'Physiology of Abiotic stress in plants'. (Ed Dwevdi and Ram) pp 79-103. (Agrobios publisher: India)
- Saleem M, Khanif B Y, Fauziah I, Samsuri A, Wahab, Hafeez B (2009) Boron status of Paddy growing areas in the state of Kedah. In 'In proceeding of Soils 2009 on Soil health: Preserving resources for sustainable Agriculture from 13-15 April, 2009 at Terengganu'. pp. 294-298 (Malaysian Society of Soil Science).
- Sajwan KS, Lindsay WL (1988) Effect of redox, zinc fertilisation and incubation time on DTPA-extractable zinc, iron and manganese. *Commun. Soil Sci. Plant Anal.* **19**, 1-11.
- Yaseen M, Khan RHN, Gill MA Aziz A, Aslam M, Khan AR (2000) Genetic variability among different rice culture for zinc uptake and utilization. *Pakistan Journal of Biological Sciences.* **3**, 1174-1176.
- Xiaopeng G, Chunqin Z, Faussuo Z, Sjoerd EA, van der Zee TM, Ellis H (2005) Tolerance of to zinc Deficiency in Rice Correlates with zinc Uptake and Translocation. *Plant and Soi.* **278**, 253-261.

Evaluation of sulphur enhanced fertilizers in a soybean-wheat rotation grown in a Brazilian Cerrado Oxisol

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Abstract

The Brazilian savannas (“Cerrado”) occupy 204 million ha with low-fertility acid Oxisols the dominant soils. Sulphur (S) deficiency is widespread in the region. Incorporation of sulphate sources (largely single superphosphate and ammonium sulphate) into fertilizer formulations leads to lower NPK concentrations and higher transport costs compared to high-analysis S-free NPK formulations. Elemental sulphur, with nearly 100% S, offers a cost-effective alternative to incorporate S into fertilizer formulations. A field experiment was carried out on a clayey Cerrado Oxisol to evaluate the agronomic efficiency of experimental “Sulphur Enhanced Fertilizers (SEF)” containing varying proportions of microfine elemental S and sulphate incorporated into granules of mono-ammonium phosphate and triple superphosphate. Powdered calcium sulphate (phosphogypsum) was used as the reference S source. Fertilizers were band applied and the fresh and residual effects evaluated in a soybean-wheat rotation for one year (two crops). Grain yields, aboveground S content, S concentration in diagnostic leaves and SPAD values were measured for both crops. There was no significant yield response to S or difference in above ground S content in the soybean crop. There was a significant response to freshly applied gypsum and SEF 774 in the wheat crop, with a higher S content in the gypsum treatment. The residual effectiveness of gypsum, and the two SEF treatments was equal in both yield and S content in the wheat crop.

Key Words

Elemental sulphur, sulphate, mineral nutrition, soil fertility, Latosols, Ferralsols.

Introduction

The savannas of central Brazil, so called Cerrados, occupy 204 million ha and correspond to approximately 24% of the national territory. It is considered one of the last and largest agricultural frontiers in the planet, and yet, the most biodiverse among the world’s savannas. Soil science has played an important role in the incorporation of the low-fertility and acid Cerrado soils into the agricultural production systems. This fact can be considered as one of the greatest achievements of agricultural research in the 20th century and is related to targeted governmental programs since the mid 1970’s, which have turned the once unproductive Cerrado soils into one of the most important agricultural regions of the country (Resck *et al.* 2008).

Rein and Sousa (2004) reported that since the mid 1950’s, when research on the fertility of Cerrado soils began, significant responses to sulphur (S) fertilization have been observed in crops and pasture yields, and quality. The high annual rainfall, large distances from the oceans, the small industrial activity in the region and the frequent natural and human-made firing of the savanna vegetation most likely explains the widespread sulphur deficiency of these soils. The widespread utilization of low or non-sulphur containing TSP, DAP, MAP and urea has resulted in an increasing incidence of S deficiency in agriculture throughout the world (Blair 2009), which is also observed in Brazil.

In the Cerrado region the main sources of sulphur are calcium and ammonium sulphates, including single superphosphate, phosphogypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and gypsite. Phosphogypsum (15% S), applied at rates between 1 to 6 t/ha depending on soil texture, is widely used as a soil amendment in the Cerrado region to alleviate the subsoil acidity, which improves chemical conditions for deep rooting. The high rates of sulphur applied as phosphogypsum have a very long nutrient residual effect, since sulphate is adsorbed in the subsurface layers of the rooting zone. However, phosphogypsum production is concentrated in few regions of the country, and the transport costs per unit of sulphur are high which is becoming an important constraint to the adoption of this technology.

Elemental sulphur, with nearly 100% S, is also used as fertilizer, supplying S to crops after oxidation to sulphate in the soil. The oxidation rate is determined by the particle size, as well as other soil factors (Boswell and Friesen 1993; Germida and Jansen 1993). The use of elemental sulphur is very limited in Brazil, despite its high agronomic efficiency observed in Cerrado oxisols when freshly applied as fine particles (Vilela *et al.* 1995; Rein and Sousa 2004). Incorporation of fine particles of elemental S into granules of NPK fertilizers offers an alternative to the use of this S source in agriculture (Boswell and Friesen 1993, Yasmin *et al.* 2007; Blair 2009). “Sulphur Enhanced Fertilizers” (SEF) have been experimentally developed by Shell, and consist of microfine particles of elemental sulphur with or without sulphate incorporated into phosphatic fertilizers. There is little information about the agronomic efficiency of SEF fertilizers in the Cerrado region. The aim of this work was to evaluate the fresh and residual effects of three SEF products as sources of sulphur in a soybean-wheat rotation in a Cerrado Oxisol.

Methods

Experimental site

A field experiment was carried out at Embrapa Cerrados (“Savannas Agricultural Research Center”), located near Brasilia in central Brazil, on a clayey red Latosol (fine, mixed, isohyperthermic Rhodic Haplustox). Soybean (cultivar BRS Valiosa RR) was grown in the period of December 2008 to April 2009 and wheat (cultivar BRS 254) from June to September 2009. The climate of the region is tropical, with mean annual temperatures and precipitation of 22°C and 1500 mm, respectively.

Prior to the establishment of the experiment the soil received dolomitic limestone to increase soil pH (water) to approximately 6.0, followed by 240 kg/ha P_2O_5 as thermalphosphate (0% S). Micronutrients and KCl were also applied to build up the fertility status. Pearl millet was planted as a cover crop in June 2008. Residues from the millet crop were quantified (above ground dry mass and sulphur concentration) and removed from the site at harvest in October 2008. The experiment started in December 2008, with treatments (S fertilizers) applied for the first crop (soybean). The experimental units (plots) had an area of 3.6 x 6 m. The experiment was cultivated under a no-till system at row spacing of 0.45 m for soybean and 0.20 m for wheat (second crop). The experiment had supplementary irrigation for soybean grown during the rainy season. The wheat crop growing during the dry season was irrigated with a sprinkler system during the whole crop cycle.

Experimental design and treatments

The experiment was performed in a randomized block design, with three replications. Eight treatments were established as shown in Table 1. SEF 881 and SEF 774 are sulphur enhanced mono-ammonium phosphate (MAP). SEF 881 (applied only in crop 1) had 9.9, 48.9 and 12.1 percent of N, P_2O_5 and S (0.6% sulphate), respectively. SEF 774 had 11.5, 43.6 and 12 percent of N, P_2O_5 and S (3.8% sulphate), respectively. TSP-S (applied only in crop 2) is a sulphur enhanced triple superphosphate with 43.1% P_2O_5 and 9.4% S (0.6% sulphate) and was tested only in crop 2. Due to differences in nutrient concentrations of the S fertilizers, rates of N and P_2O_5 were balanced for all treatments. Powder phosphogypsum (17.5% of sulphur as sulphate on a dry basis) was used as a sulphur reference source. The SEF fertilizers were applied at 20 kg S/ha, which is in the recommended range of 15-30 kg/ha for most crops in S-deficient Cerrado soils (Rein and Sousa 2004). Gypsum was applied at 20 and 40 kg S/ha.

Plant sampling and analysis

SPAD values were measured using a SPAD-502 chlorophyll meter on the diagnostic leaves (newly expanded leaf from the top to the shoot) of soybean and wheat during the flowering period. Grain yield (kg/ha), sulphur concentrations in the diagnostic leaves (g/kg), SPAD values and sulphur content in the above ground dry mass (grain plus straw, kg) were measured and statistically analysed using PROC GLM by SAS (SAS Institute 1996). Plant tissues were digested with $HClO_4-H_2O_2$ and sulphur analysed by ICP-AES. The treatments were compared by Tukey test ($P < 0.05$). Apparent fertilizer recovery was computed as: $\{[(\text{aboveground S content of fertilizer treatments} - \text{aboveground S content of control treatment}) / \text{fertilizer S applied}] \times 100\}$.

Results

Few visual symptoms of sulphur deficiency were observed in soybean (crop1), expressed by somewhat shorter plants in no-S (1) and SEF 881 (4) treatments (data not shown). The youngest leaves were not chlorotic, and no differences in SPAD values were observed (Table 2). Batista and Monteiro (2007) studying the sulphur and nitrogen fertilization, and their concentrations in leaf tissue of Marandu grass (*Brachiaria*

brizanta) reported that SPAD values were influenced by the S supply. In crop 2, the wheat plants for the no-S treatment (1) were shorter, with chlorosis in the whole plant. Sulphur nutrition status of wheat evaluated by SPAD values and S concentration of the diagnostic (flag) leaf (Table 2) showed that these variables were significantly correlated (Person correlation coefficient $r=0.78$).

In Crop 1 (soybeans), there was no significant difference in yield between the control and S sources (Table 1). Although differences were not significant, it appeared that SEF 881 was less effective than gypsum, as shown by the lower yield and aboveground S content. SEF 774 was not significantly different from gypsum. Evaluating the residual effect of these treatments in crop 2 (wheat), SEF 881 was as effective as gypsum. In crop 2 (wheat), a fresh application of gypsum at 20 kg S/ha or the residual effect of 40 kg S/ha resulted in grain yield responses of 38% and 30%, respectively, compared to the control treatment. Although grain yields in the SEF 774 treatments did not differ significantly from gypsum when applied at a fresh rate of 20 kg S/ha in crops 1 and 2, SEF 774 had a lower S concentration in the diagnostic leaf and a lower S content in the aboveground dry matter for the wheat crop, evidencing its lower initial effect compared to gypsum (Table 1). Blair (2009) reported that, of 84 experiments conducted to evaluate experimental SEF fertilizers in different countries, the yield responses to SEF were the same, exceeded or less than sulphate S at 50, 28 and 6 sites, respectively.

Table 7. Effect of sulphur enhanced fertilizers in the grain yield, sulphur concentration in the diagnostic leaves (S Leaves), SPAD values (SPAD) and sulphur content in the above ground dry matter (S content) in a soybean/wheat rotation grown in a Brazilian Cerrado Oxisol.

Crop 1 (Soybean)					Crop2 (Wheat)				
Treatment	Grain yield (kg/ha)	S leaves (g/kg)	SPAD	S content (kg)	Treatment	Grain yield (kg/ha)	S leaves (g/kg)	SPAD	S content (kg)
Control	3057 ab	1.48 ab	40.1 a	8.2 bc	Control	2197 c	1.37 d	35.7 d	2.5 b
MAP	3052 ab	1.53 ab	39.9 a	7.9 bc	SEF 774	2583 abc	1.92 bc	43.9 ab	3.9 b
MAP	2960 ab	1.60 ab	40.0 a	7.0 c	Gypsum	3035 a	2.79 a	44.9 a	5.5 a
SEF 881	2922 b	1.34 b	40.1 a	6.3 c	MAP	2724 abc	1.69 cd	38.6 bcd	3.5 b
SEF 774	3130 ab	1.40 b	41.0 a	8.9 bc	MAP	2488 abc	1.65 cd	37.4 cd	3.7 b
Gypsum 20S	3369 a	1.79 ab	42.7 a	10.8 ab	MAP	2633 abc	1.62 cd	38.4 cd	3.3 b
Gypsum 40S	3340 a	1.93 a	40.9 a	13.1 a	MAP	2861 ab	2.23 b	41.8 abc	4.0 b
MAP	3012 ab	1.49 ab	40.4 a	7.9 bc	TSPS	2270 cb	1.66 cd	37.3 cd	3.4 b
CV (%)	4.7	10.7	2.9	12.2		8.3	9.8	4.8	13.7

Both SEF 881 and TSP-S have predominately elemental sulphur incorporated into the granules, whereas in SEF 774 one-third of the incorporated S is sulphate. A slow oxidation rate of the elemental sulphur in SEF 881 applied for crop 1 would explain why this fertilizer became more effective in supplying sulphur for crop 2 (Table 2). It would also explain why TSP-S applied in crop 2 did not improve the grain yield of wheat. Results from previous experiments in the same site and soil showed that powdered elemental sulphur was as effective as gypsum in supplying sulphur to grain crops (Vilela *et al.* 1995; Rein and Sousa 2004). The reasons why finely ground elemental sulphur incorporated into the present fertilizers (SEF 881 and TSP-S) was less effective compared to calcium sulphate when freshly applied needs further investigation. Elemental S oxidation is governed by its particle size and a number of soil factors (Boswell and Friesen 1993; Germida and Jansen 1993) and the data presented here suggests that the soil environment in and around the granule zone after its dissolution should be studied further.

The apparent S-fertilizer recovery (Table 2), computed from S contents in the aboveground dry matter showed similar values for freshly applied gypsum, around 15%, for both soybean and wheat crops, which is higher than recoveries observed for the other sulphur sources. On the other hand, the residual apparent S-fertilizer recoveries in crop 2 were similar for gypsum, SEF 881 and SEF 774.

The residual effects and responses to reapplication of the tested S-fertilizers will be evaluated for one more soybean-wheat cycle in this ongoing experiment.

Table 2. Apparent S-fertilizer recovery in a soybean/wheat rotation grown in a Brazilian Cerrado Oxisol.

Crop 1	Crop 2	Apparent Fertilizer Recovery (%)	
Soybean	Wheat	Soybean	Wheat
Control	Control	-	-
MAP	SEF 774	-	6.7
MAP	Gypsum	-	14.9
SEF 881	MAP	-7.3	4.8
SEF 774	MAP	5.9	5.2
Gypsum 20S	MAP	15.3	3.6
Gypsum 40S	MAP	13.3	3.6
MAP	TSPS	-	4.2

Conclusion

The tested Sulphur Enhanced Fertilizers based predominately on elemental sulphur incorporated into granules of mono-ammonium phosphate and triple superphosphate produced lower yield or sulphur uptake responses compared to gypsum when freshly applied, but nearly equivalent residual effects for the second crop.

References

- Batista K, Monteiro FA (2007) Nitrogen and sulphur in marandu grass: relationship between supply and concentration in leaf tissues. *Scientia Agricola* **64**, 44-51.
- Blair GJ (2009) Sulphur Enhanced Fertilizer (SEF) – A new generation of fertilizers. In ‘Proceedings of the 16th International Plant Colloquium’. (UC Davis) <http://escholarship.org/uc/item/16h5b2dm>
- Boswell CC, Friesen DK (1993) Elemental sulfur fertilizers and their use on crops and pastures. *Fertilizer Research* **35**, 127-149.
- Germida JJ, Jansen HH (1993) Factors affecting the oxidation of elemental sulfur in soils. *Fertilizer Research* **35**, 101-114.
- Rein TA, Sousa DMG (2004) Adubação com enxofre. In ‘Cerrado – Correção do Solo e Adubação’. (Eds. DMG Sousa, E Lobato), pp. 227-244. (Embrapa Informação Tecnológica, Brasília).
- Resck DVS, Ferreira EAB, Santos Junior JDG, Sá MAC, Figueiredo CC (2008) Manejo do solo sob um enfoque sistêmico. In ‘Savanas – Desafios e Estratégias para o Equilíbrio entre Sociedade, Agronegócio e Recursos Naturais’ (Eds. FG Faleiro, AL Farias Neto), pp. 416-473. (Embrapa Cerrados, Planaltina).
- SAS Institute (1996) SAS/STAT user's guide, version 6.11, 4th ed. Cary (Statistical Analysis System Institute: NC).
- Vilela L, Ritchey KD, Silva JE (1995) Sulphur response of soybean and corn in Clayey Dark Red Latosol of the Brazilian Cerrados. *Revista Brasileira de Ciência do Solo* **19**, 281-285.

Fertiliser nitrogen requirements reduce as soil organic matter accumulates following modification of podzolised soils in New Zealand.

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Abstract

Humping & hollowing is a land development practice used in the high rainfall West Coast region of South Island of New Zealand to improve drainage and pasture dry matter production (DMP) of podzolised soils. The resultant soils and landforms are radically different from the original landscape. On-farm field trials were established to investigate how DMP was affected by the time following modification (1, 5 and 10 years) and how position (i.e. humps, slopes and hollows) and fertiliser N rates (0 to 480 kg N/ha/yr) affected this response. SOM increased with time, with most accumulation in the humps and slopes. The amount of DMP was greatest on the older modified soils and more DMP was produced on the humps and slopes. DMP per unit of fertiliser N applied was much lower in the newer soils than the older soils. Building up SOM in these recently modified soils is important for nutrient cycling and especially for supplying nutrients. This information can help farmers adjust N fertiliser applications in more targeted ways leading to more efficient N use and reduced environmental risks of nutrient losses from these soils.

Key Words

Nitrogen, fertiliser, soil carbon, pasture production.

Introduction

Poor drainage is a major agricultural production constraint for large areas of West Coast “pakihi” soils of the South Island of New Zealand. These soils are acidic, infertile and podzolised with distinct impermeable iron pans. To overcome water-logging and nutrient availability constraints in this high rainfall environment an extreme landform modification - humping and hollowing is practiced. Large machinery is used to excavate the “hollows”, removing the soil and breaking through the upper iron pans, creating wide surface drains. The “humps” are built up from the excavated spoil deposited on to the original soil surface. This practice drastically alters the landscape with the hump-hollow sequence recurring every 20 to 30 m across the farmland. The height difference from the bottom of the hollow to the top of the hump is about 3 m; the actual gradient of the contours depends on the depth to the iron pan. The wide hollows underlain by impermeable iron pans and the increased relief of the humps improve the surface drainage and thereby reduces water-logging. This practice has increased the productive capacity of the land and in particular has enabled dairy expansion in the West Coast region over the last twenty years. However, land managers have very little information on how to manage the modified soils of these new landforms.

A recent fertiliser response study by Morton and Roberts (2006) on newly modified “pakihi” soils concluded that high rates of N, P and K are required to maximise dry matter production (DMP) in the early stages of post-modification development. In another study, the amount and quality of soil organic matter was found to rapidly increase from low levels post-modification; total soil C range from about 10 t C/ha post modification to 45 t C/ha ten years after modification (Thomas *et al.* 2007). They also found that the rates of accumulation were affected by the landform type, i.e. humps accumulated organic matter faster than hollows.

These findings have important implications for managing nutrients for pasture production. In this study we report the results from field trials established to understand how the changes in soil organic matter following soil modification affect nutrient supply and in turn the fertiliser N requirements for pasture growth.

Methods

Field trials were conducted on three dairy farms that had extensive areas of hump and hollowing of a range of ages since modification located within 35 km of Greymouth on the West Coast of the South Island. The annual rainfall in this area is typically >2500 mm per year and the mean annual temperature at Greymouth is 12.1 °C.

The objectives of the field trials were to determine how dry matter production (DMP) responded to the age of the trial site (time since modification), position on the landform (hump, slope or hollow) and to fertiliser rates. Field trials were established on nine hump and hollow sites across the three farms. The experiment was designed as a randomised split criss-cross design. The main treatment was time since modification (Age) with three Ages - 1, 5 and 10 years since hump and hollowing and three replicates of each. Each of these nine sites was made up of fifteen 4 m long x 1 m wide plots with three Position treatments (hump, slope and hollow) and five N treatments (0, 120, 240, 360, 480 kg N/ha/yr) applied in a criss-cross layout. Typically the distance from the midpoint of the hollow to the midpoint of the hump was 16 m. The slope plots were midway between the hollow and the hump plots. N fertiliser rate plots ran horizontally across the hump and hollow sequence. There was at least a 1 m buffer between plots.

Fertiliser N treatments (as urea) were applied starting in late-winter (August 2008) until late autumn (May 2009) with the number of applications varied depending on the N treatments and were applied at rates of 40 or 60 kg N/ha with the applications timed to meet anticipated seasonal pasture requirements. Animals were excluded from the field trial sites throughout the trial, and three months previously, to reduce the effect of residual N from urine and dung on dry matter responses to the N. Dry matter production was determined 11 times between August 2008 and July 2009 from mown strips taken from each plot. Total soil C and N were determined from duplicate soil samples (0 to 15 cm) in February 2009 at each of the three positions (hump, slope and hollow) at the nine sites. Treatment effects on total soil C and N and dry matter production were analysed by ANOVA; an estimate of the variability associated with estimated means are given by 5% Least Significant Differences (LSDs).

Results

There is strong indication that soil organic matter was rapidly increasing with time after modification (Table 1). Levels of soil C and N after 10 years were about twice those of the 1 year old sites for all positions. The amounts of soil C and N were also affected by Position ($p=0.001$) as well as time, i.e. there was more soil C and N in the humps and slopes than the hollow, and that the rate of SOM accumulation was greatest in the humps than the slopes and hollows (Table 1). The range of total soil C did not vary greatly between Position at the first year post-modification sites (with a C range of 1.8%), whereas, after five and ten years following modification the differences in total soil C and N between Position was much greater (with a total soil C range of 3.2 and 2.9 % for the 5 year and 10 year Age plots, respectively).

Table 1. Total soil Carbon and Nitrogen (%) levels (0-15cm) from sites of three different ages since modification (3 reps) measured from humps, slopes and hollows.

Years since modification	Hollow	Slope	Hump	LSD (5%, 12 df)
<i>Carbon</i>				
1	2.16	4.05	3.28	3.03
5	3.27	5.88	6.55	
10	4.20	6.52	7.06	
<i>Nitrogen</i>				
1	0.10	0.19	0.17	0.17
5	0.20	0.36	0.41	
10	0.31	0.44	0.48	

Both Age and Position affected DMP (Figure 1). Most dry matter was grown on the older plots and least on the newly developed soil. Most dry matter was produced on the humps followed by slopes then hollows e.g. for the zero N treatment there was 53% more DMP in the humps than the hollows.

Fertiliser N had a strong effect on the DMP ($p<0.001$), DMP increased approximately linearly with increasing N fertiliser rates up to the highest N rate of 480 kg N/ha/yr. These results indicate that more N fertiliser is required in the humps and hollows in the 1 year old plots to grow dry matter than the humps and hollows in the 10 year old plots. For example, 2500 kg DM/ha more was produced on the humps after 10 years post-modification that had 240 kg N/ha/yr applied than the 1 year old plots. Importantly, there was a large difference in DMP between plots of different ages which had no fertiliser N applied (Figure 1), especially on the humps. This has important fertiliser and production management implications. For example, in order for the 1-5 year old sites to reach the same DMP on the humps as the 10-year-old site without N applied, 400 kg of N would need to be applied.

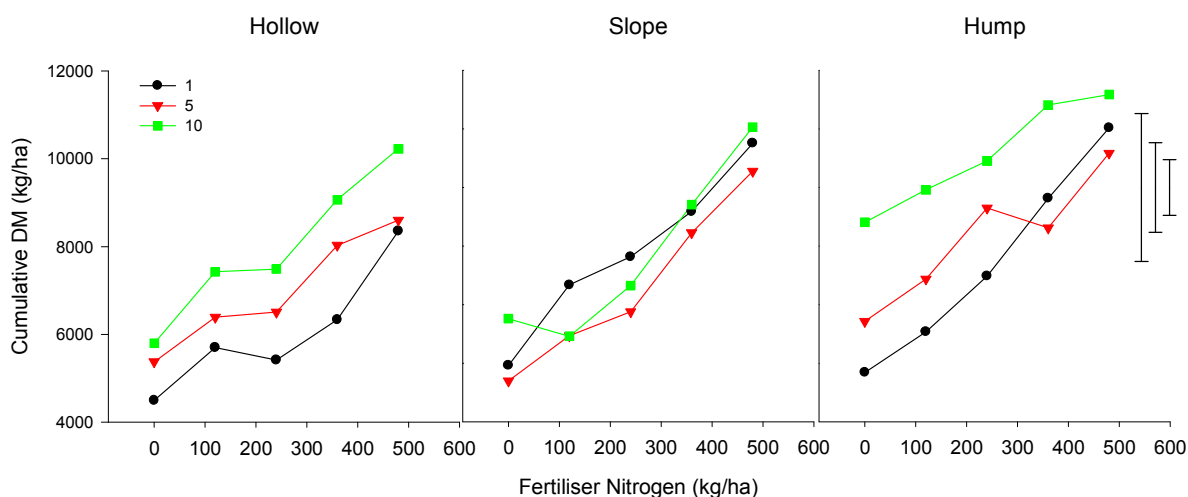


Figure 1. The effect of Position, Age, N fertiliser on DMP. Bars represent 5% LSDs; the largest applies to all values, the next should only be used when comparing effects of age and N and the smallest only when comparing effects of age and position.

The differences in DMP affected by Age and Position followed a similar pattern to the increase of total soil C and N. This suggests that increases in DMP are strongly affected by the accumulation of SOM. Lower DMP in the hollows is most likely to be a function of the low levels of SOM as the original soil was removed and deposited to construct the humps. Low SOM levels would affect pasture growth by limiting the cycling and supply of nutrients and the ability of the soil to store water.

Conclusion

Following humping and hollowing the newly formed soils have low SOM. However, SOM may accumulate rapidly over a relatively short time frame (ten years). As SOM accumulates, the annual rates of DMP also increase. While high rates of application of fertiliser N will increase DMP in newly modified soils, the amount of dry matter produced per kg of fertiliser N added will still be much lower than on the older modified soils. Building up SOM in these recently modified soils is important for nutrient cycling and especially for supplying nutrients. In addition to building up soil organic matter and nutrient cycling over time, the position on the hump and hollows also affects both SOM accumulation and DMP.

These findings have implications for soil nutrient management. Pasture fertiliser requirements will change as soils develop and will depend on whether the soil is part of the hump, slope or hollow. Current fertiliser application practices do not take into account the changing SOM status and treat the humps and hollows in the same way. Based on these findings there is an opportunity to manage the soil fertility and fertiliser applications in more targeted ways to meet pasture production needs. This information can be used to help inform farmers of the benefits of adjusting N fertiliser rates for pasture production and lead to more efficient N use and reduced environmental risks of nutrient losses on these modified soils.

References

- Morton JD, Roberts AHC (2006). Pasture responses to fertiliser on renovated West Coast pakihi soils. *Proceedings of the New Zealand Grassland Association* **68**, 331–338.
- Thomas SM, Beare MH, Ford CD, Rietveld V (2007). Changes in soil quality following humping/hollowing and flipping of pakihi soils on the West Coast, South Island New Zealand. *Proceedings of the New Zealand Grassland Association* **69**, 265–270.

Fertilizer best management practices in the dryland Mediterranean area – concepts and perspectives

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Abstract

While globally fertilizers have had a major impact on food production for the past half-century, the general use of chemical fertilizers in the semi-arid areas of the world is a more recent development. This is particularly true of the Mediterranean region, especially in North Africa and West Asia. Traditionally, the cropping system involved growing cereals (barley and wheat) in rotation with fallow to conserve moisture; sheep and goats were an integral part of the low-input system. Drought was a constant constraint on crop yields. In the past few decades, significant developments have occurred to increase agricultural output; new high-yielding disease resistant varieties; mechanization; irrigation; pest control; and particularly the use of chemical fertilizers as a supplement to the limited animal manures available. Research at the International Center for Agricultural Research in the Dry Areas (ICARDA) in collaboration with the national agricultural systems in the mandate countries of the region has made significant strides in fertilizer research. While much has been achieved in terms of best fertilizer management practices, much remains to be done. This presentation examines the use of fertilizers under the headings of the best management practice concept; right source, right application rate, right time of application, and right place. As fertilizer use will expand in the Mediterranean region, efficiency of use will be an underlying consideration.

As agricultural land on a global level is finite, with limited possibilities to expand cultivation, the increasing population of the world has correspondingly increased the needs for food and fibre. An inevitable development has been intensification of land use, particularly in developing countries of the world, leading to poverty and increased concerns about food security (Borlaug 2007). Pressure on land has been particularly acute in the arid and semi-arid regions, which are characterized by drought and land degradation.

The lands surrounding the Mediterranean have been cultivated for millennia and are the site of settled agriculture and the center of origin of some of the world's major crops, especially cereals and pulses. Much development efforts have centered on the West Asia- North Africa (WANA) area, which is characterized by a Mediterranean climate and where drought is the main production constraint (Smith and Harris 1981).

Rainfall and Cropping Systems

Under typical Mediterranean conditions, rainfed cropping is only possible during the cool, wet "winter" season (late fall-early summer) with growth dependent on the amount of rainfall which is variable between and within years. In addition, fallowing, or cropping in alternate yields (Harris 1995), has been a hedge against drought in order to increase the likelihood of an economically harvestable crop, especially in below-average rainfall years. Limited summer cropping can occur when there is carryover of sufficient moisture, while a full range of crops can be grown where irrigation is available. Typical rainfall and temperature conditions that dictate rainfed cropping are illustrated in Figure 1. The normal rainfed pattern varies from year to year and within season. As a consequence, drought is invariably a constraint on crop production. In addition to inherent agroecological constraints associated with this region (Kassam 1981), such as a wide range of soil types of varying fertility and depth (Matar *et al.* 1992), there are numerous socioeconomic obstacles to sustainable agricultural development. The cropping system that has evolved under low rainfall conditions of the Mediterranean climate is centered on dryland or rainfall cereals (Cooper *et al.* 1987), with bread wheat (*Triticum aestivum*) and durum wheat (*T. durum*, var *turgidum*) in the more favorable rainfall zones (350-500 mm) and barley (*Hordeum vulgare*) being dominant in the lower rainfall areas as it is relatively drought-tolerant. Both food legumes, such as chickpea (*Cicer arietinum*), lentil (*Lens culinaris*) and faba bean (*Vicia faba*), a pasture and forage legumes such as vetch (*Vicia sativa*) are significant in maintaining the agriculture of the region. Crop rotations involving legumes are an alternative to fallow and continuous cropping, both economically and biophysically (Ryan *et al.* 2008a). The typical Mediterranean conditions involve cereal production integrated with livestock, mainly sheep

Agroecological conditions across the Middle East range from deserts and rangeland in arid areas (less than 200 mm) to barley-based systems (200-350 mm) and then wheat based systems (350-500 mm) and wider cropping options above that.

The Changing Context

Agriculture in the WANA region has greatly changed in the past few decades, with a shift from traditional agriculture to more intensive cropping, particularly in terms of chemical inputs, especially fertilizers. Most countries of the region have had increased use of nitrogen (N) and to a lesser extent phosphorus (P), reflecting the crop needs, but little potassium (K) use due to high available K reserves in the soils. Micronutrients are rarely used.

Methodology

As our concern is fertilizer best management practices, we briefly indicate the relevance of components of such practices. These are based on numerous soil fertility/agronomy/plant nutrition studies as reported in various reviews of N (Ryan *et al.* 2009), P (Matar *et al.* 1992; Ryan *et al.* 2008b), and micronutrients (Rashid and Ryan 2008).

Results

Right Time

- Due to limited rainfall and thus leaching losses, there was generally little difference between fall and spring application of N fertilizers. However, topdressing in spring allowed more flexibility in relation to rainfall.

Right Place

- Response to N fertilizer was related to increasing rainfall and soil moisture availability. In Syria, responses were highest where rainfall was favorable (350-500mm) and minimal below 250 mm. Responses to N were highest after fallow and lowest after continuous wheat.
- Responses to P were related to fields where soil test levels for P were low; in areas where P had buildup from regular fertilization, there was little or no response to fertilization. Hence, the importance of soil testing in identifying areas of likely fertilizer response is illustrated.
- Responses to N are also conditioned by the level of soil organic matter, which in turn are related to the particular crop rotation that has been practiced in the area or field (Ryan *et al.* 2010).
- Similarly, crop responses to N and P fertilization only occur where there are no deficiencies of micronutrients, such as zinc or iron, or toxicities, such as that of boron.

Right Source

- While urea has become the dominant N fertilizer, it is prone to volatile loss, however, if mixed into the soil or applied under cooler conditions or topdressed before or during spring rains, loss is minimal (Abdel Monem *et al.* 2010).

Right Application Method

- While all soluble P sources are “fixed” by calcareous soils, efficiency is improved by banding. Buildup can occur quickly and efficiency may be higher if the long-term is considered. Conservation or minimum tillage and irrigation require modifications in fertilizer application methods.

Right Application Rate

- Numerous soil test calibration studies from countries of the WANA region identified appropriate application rates for N and P for various crops under rainfed and irrigated conditions, being higher in the latter conditions. Nutrient levels were identified to give optimum crop yield response, but avoid excess nutrient use, especially for N.

Conclusions

Fertilizer use will increase in the cropping systems of the region. Given the costs of the materials and the environmental implications, efficiency of nutrient use will assume major importance. This can only be achieved by considering the various site-specific factors (rainfall, soil types, nutrient test levels, the particular crop, method of tillage, irrigation) that affect efficient nutrient use.

References

- Abdel Monem M, Lindsay WL, Sommer R, Ryan J (2010) Loss of nitrogen from urea applied to rainfed wheat in varying rainfall zones in northern Syria. *Nut. Cycl. Agroecostst.* **86**, 357-366.
- Borlaug NE (2007) Feeding a hungry world. *Science* 318:359.
- Cooper PJM, Gregory PJ, Tully D, Harris HC (1987) Improving water-use efficiency for annual crops in the rainfed farming systems of West Asia and North Africa. *Expl. Agric.* **23**, 113-158.

- Harris HC (1995) Long-term trials on crop and soil management at ICARDA. *Adv. Soil Sci.* **19**, 447-469.
- Kassam AH (1981) Soil, climate and land resources in North Africa and West Asia. *Plant and Soil* **58**, 1-29.
- Matar A, Torrent J, Ryan J (1992) Soil and fertilizer phosphorus and crop responses in the dryland Mediterranean zone. *Adv. Soil Sci.* **18**, 82-146.
- Rashid A, Ryan J (2008) Micronutrient constraints to crop production in the Near East: potential significance and management strategies. In 'Micronutrients deficiencies in global crop production'. (Ed RJ Alloway) pp. 149-180. (Springer, Dordrecht, The Netherlands).
- Ryan J, Singh M, Pala M (2008a) Long-term cereal-based rotation trials in The Mediterranean region. Implications for cropping sustainability. *Adv. Agron.* **97**, 276-324.
- Ryan J, Ibrikci H, Singh M, Matar A, Masri S, Rashid A, Pala M (2008b) Response of residual and currently applied phosphorus in dryland cereal/legume rotations in three Syrian ecosystems. *Eur. J. Agron.* **28**, 126-137.
- Ryan J, McNeill A, Ibrikci H, Sommer R (2009) Nitrogen in irrigated and rainfed cropping systems of the Mediterranean region. *Adv. Agron.* **40**, 53-136.
- Ryan J, Pala M, Harris H, Masri S, Singh M (2010) Rainfed wheat-based rotations under Mediterranean-type climatic conditions: Crop sequences, N fertilization, and stubble grazing intensity in relation to cereal yields parameters. *J. Agric. Sci. (Camb.)* **48**, 205-216.
- Smith RG, Harris HC (1981) Environmental resources and constraints to agricultural production in a Mediterranean-type environment. *Plant and Soil* **58**, 31-57.

Greenwaste biochar potentially reduces nitrogen fertiliser losses

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Abstract

This study determined the maximum NH_4^+ -N sorption capacity for greenwaste biochar to be 909 mg/kg, equating approximately to a maximum increase in soil NH_4^+ -N storage of just under 1kg for each tonne of biochar applied to the soil. Over 90% of the sorbed NH_4^+ -N was recovered from the biochar by extraction with 2M KCl indicating that the sorbed NH_4^+ -N was exchangeable and plant available. When applied in large quantities (up to hundreds of tonnes) it has potential to reduce losses of mineral nitrogen (N) when in the NH_4^+ -N form prior to nitrification. This characteristic of the biochar would account for a significant proportion of the improvements in N fertiliser use efficiency noted in several pot trials. Biochar NO_3^- -N retention may have also contributed. Our study has also demonstrated that the impact of the greenwaste biochar is greatest on light sandy soils with naturally low NH_4^+ -N retention properties, and that these soils along with weathered tropical soils with low CEC should be targeted for biochar applications, to maximise environmental and economic benefits.

Key Words

Greenwaste, biochar, nitrogen, ammonium, isotherm.

Introduction

Biochars (high carbon materials produced from the slow pyrolysis of biomass) have recently come to prominence because of their potential for sequestering atmospheric carbon to the soil due to the relative stability of biochar organic carbon (Lehmann *et al.* 2006, Lehmann and Joseph 2009). The high fertility of *terra preta* soils in the Amazon has been associated with their high organic carbon content in the form of char originating from the 'slash and char' practice of the pre-Columbian indigenous people of the area (Glaser *et al.* 2001). A series of recent pot trials (Chan *et al.* 2007, Chan *et al.* 2008, van Zwieten *et al.* 2010) have demonstrated higher crop yields with increasing rates of biochar application in the presence of N fertiliser, demonstrating a N fertiliser use efficiency benefit from biochar. This improved N fertiliser use efficiency has been attributed to improved soil physical conditions, liming effect, and increased CEC, but no direct measurements of biochar mineral N retention were done. This study focused on greenwaste biochar with a silty clay loam soil from Camden NSW and a sandy loam soil from Somersby, NSW. A NH_4 -N retention isotherm was determined for this greenwaste biochar to determine the biochar's maximum NH_4 -N sorption capacity. In addition, soil-biochar mixtures were equilibrated with an NH_4^+ -N solution to ascertain the biochar impact on NH_4 -N retention in two soil types.

Methods

Soil and greenwaste biochar characteristics

Table 1. Basic chemical properties of the greenwaste biochar and the two soils used in this study.

	Texture	EC	pH _w	N (%)	C (%)	Bicarb. P (mg/kg)	NH_4^+ -N (mg/kg)	NO_3^- -N (mg/kg)	ECEC (cmol/kg)
Char		0.06	5.9	0.15	65	43	13	<0.2	
Soil A	ZCL	0.06	5.6	0.18	2	26	6	59	8.7
Soil B	SL	0.07	6.3	0.17	1.9	150	7	30	6.8

Determining the NH_4 -N sorption isotherm for the greenwaste biochar

Standard solutions of NH_4^+ -N were made up using ammonium sulphate $[(\text{NH}_4)_2\text{SO}_4]$ and deionised water with 0, 4, 10, 20, 40, 80, and 160 mg NH_4 -N / L. A 30 mL aliquot of each of these solutions was added to a 2.0 g o.d.e sample of air dry greenwaste biochar in a 40 mL centrifuge tube and done in duplicate. The tubes of biochar and NH_4^+ -N solutions were then shaken end over end for 20 h to ensure equilibration. The samples were then centrifuged in a high speed centrifuge at 10,000 rpm for 15 min, before pouring off the supernatant through a Whatman 42 filter paper for analysis. Filtered supernatant samples were analysed for

NH₄⁺-N and NO₃-N using a Lachat Quickchem automated ion analyser (QuickChem method 10-107-064-D for NH₄⁺ and 10107-04-1-H for NO₃⁻/NO₂⁻).

A 40 mg/L NO₃⁻-N standard solution was also made up with KNO₃ to assess NO₃⁻-N retention by the soil, and duplicates of 30 mL of this solution and 2.0 g o.d.e biochar samples were run with the above NH₄-N samples and treated identically.

A similar methodology to that outlined by Sharpley *et al.* (2008) for calculating P sorption isotherms for soil was followed to determine the isotherm for NH₄-N retention/sorption by the biochar. The total NH₄-N (mg/kg) sorbed by the char (S) = S₁(NH₄-N sorbed by the soil in the 20 h equilibration) + S₀ (Previously sorbed NH₄-N). For the purpose of this calculation, we used 2 M KCl extracted NH₄-N for the char (i.e. 13 mg/kg) as the S₀ value. The Langmuir isotherm for NH₄-N was created by plotting the mean total sorbed NH₄-N mg/kg (S) against solution NH₄-N concentration (mg/L) for the duplicate samples. The equilibrium NH₄-N concentration (ENH₄-NC₀ mg NH₄-N/L), defined as the concentration supported by the biochar sample at which no net sorption or desorption occurs, was calculated as the intercept of the isotherm curve on the x-axis of this graph. The NH₄-N sorption maximum (S_{max}, mg NH₄-N kg biochar) and the binding energy of NH₄-N to the biochar (k, L mg NH₄ /N) were graphically determined based on the Langmuir sorption equation (1)

$$C/S = 1/[kS_{\max}] + C/S_{\max} \quad (1)$$

where S is the total amount of NH₄-N sorbed to the biochar (mg NH₄-N / kg biochar), C is the equilibrium solution concentration after 20 h shaking (mg NH₄-N / kg biochar), S_{max} is the NH₄-N sorption maximum (mg NH₄-N /kg biochar), and k is a constant relating the binding energy of NH₄-N to biochar (L /mg NH₄-N). The graphical determination of these parameters was based on that outlined by Sharpley *et al.* (2008) that involved plotting C/S vs. C with NH₄-N sorption maximum (S_{max}) being calculated as the reciprocal of the slope of this plot, and the binding energy (k) being calculated as the slope / intercept of this plot.

Estimating the availability of NH₄-N adsorbed by the biochar to plants

Following decanting of the supernatant NH₄-N solutions from the biochar at the end of the 20 h equilibration period, the biochar samples in the centrifuge tubes were extracted with (i) 20 mL deionised water (wash) shaken end over end for 20 min, (ii) 20 mL 0.01 M CaCl₂ shaken for 1 h, (iii) 20 mL 2M KCl shaken for 1 h and (iv) a second extraction with 2 M KCl shaken for 1 h. After each shaking, the samples were centrifuged for 15 min at 10,000 rpm and the supernatant decanted and filtered through a Whatman 42 filter paper for analysis for NH₄-N and NO₃-N. The amount of NH₄-N sorbed by the biochar deemed to be plant available was calculated by adding together the NH₄-N in the supernatant solutions for extractions (ii) and (iii) and then subtracting the original biochar sorbed (KCl extractable) NH₄-N value of 13 mg/kg. The second KCl extraction was thought to represent NH₄-N that would become available to plants with time. The 40 mg/L NO₃-N duplicate char samples were also assessed for NO₃-N retention with the same extraction regime as outlined above for the NH₄-N samples.

Biochar impact on soil NH₄-N adsorption

Samples of the two soil types being studied were chloroform fumigated as done for microbial biomass determination (Vance *et al.* 1987), in order to impede soil microbial activity and associated nitrification of NH₄-N added to the soils. Greenwaste biochar was added to 2.0 g o.d.e of the two fresh fumigated soils (< 2 mm) in a centrifuge tube at rates of 0, 0.28, and 0.56 g o.d.e to create 6 treatments. Assuming a bulk density of 1.2g/cc and an incorporation depth of 10 cm, the six treatments were equivalent to char application rates of 0, 168, and 335 t/ha. The resultant treatments were (i) Soil A only, (ii) Soil A + 168 t/ha biochar, (iii) Soil A +335 t/ha biochar, (iv) Soil B only, (v) Soil B + 168 t/ha biochar, and (vi) Soil B +335t/ha biochar. Each treatment had three replicates. A 30 mL aliquot of the 40 mg NH₄-N /L solution was added to each sample, and the samples were shaken end over end for 10 h to allow equilibration between the NH₄-N solution and the soil-biochar samples. After shaking the samples were centrifuged for 15 min at 2000 rpm before the supernatant was filtered through a Whatman 42 filter paper, and analysed for NH₄-N and NO₃-N using the method previously outlined. The difference between the NH₄-N in the 40 mg NH₄-N / L solution added to the soil-char treatments and the 20 h equilibrated supernatant solution for each sample was calculated as being the NH₄-N sorbed by the soil, and expressed on a mg/kg of dry soil basis. A one way ANOVA was carried out on this data set, and treatment means compared using least significant difference(LSD), with differences considered significant at *P*=0.05.

Results

The Langmuir sorption isotherm for $\text{NH}_4\text{-N}$ and greenwaste biochar and associated parameters determined by this study are presented in Figure 1. The $\text{NH}_4\text{-N}$ sorption maximum for biochar was determined to be 909 mg/kg (Figure 1b). This equates to a maximum increase in soil $\text{NH}_4\text{-N}$ storage capacity of just under 1 kg for each tonne of greenwaste biochar applied to the soil. The 0.01 M CaCl_2 extraction and the first 2 M KCl extraction recovered between 71% and 89% of $\text{NH}_4\text{-N}$ adsorbed by the biochar (Table 2) suggesting that the majority of the $\text{NH}_4\text{-N}$ adsorbed by the biochar is exchangeable and plant available. Except for the highest concentration $\text{NH}_4\text{-N}$ solution treatment, >90% of the $\text{NH}_4\text{-N}$ adsorbed by the char was recovered after the 2nd 2 M KCl extraction (Table 2), suggesting that only a very small proportion of the $\text{NH}_4\text{-N}$ adsorbed by the biochar is likely to be unavailable to plants in the medium term. A curious result was that the biochar was found to adsorb 129 mg/kg of $\text{NO}_3\text{-N}$ from the 40 mg/L $\text{NO}_3\text{-N}$ solution indicating the possible presence of some anionic exchange capacity in the biochar. This was less than half the amount of $\text{NH}_4\text{-N}$ that was adsorbed by the biochar from $\text{NH}_4\text{-N}$ solution of the same concentration.

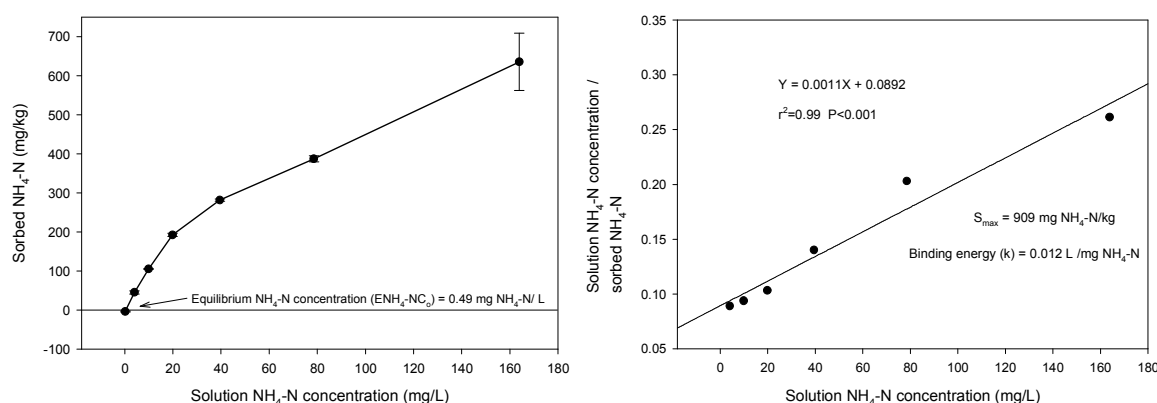


Figure 1. The Langmuir $\text{NH}_4\text{-N}$ sorption isotherm for greenwaste biochar-mean values with SE bars (a), and a plot of C/S vs. C with derived values of maximum $\text{NH}_4\text{-N}$ sorption (S_{max}) and bonding energy (k) for the greenwaste biochar (b).

Table 2. Recovery of adsorbed $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ from biochar in 0.01 M CaCl_2 and 2 M KCl extractions.

Solution $\text{NH}_4\text{-N}$ (mg/L)	$\text{NH}_4\text{-N}$ adsorbed (mg/kg char) [mean $\pm$ SE]	$\text{NH}_4\text{-N}$ recovered in Extracts 1 and 2 ^A (mg/kg char) [mean $\pm$ SE]	Adsorbed $\text{NH}_4\text{-N}$ recovered in extracts 1 and 2 (%)	$\text{NH}_4\text{-N}$ recovered in extract 3 ^A (mg/kg char) [mean $\pm$ SE]	Adsorbed $\text{NH}_4\text{-N}$ recovered in extracts 1, 2 and 3 (%)
0	-16 $\pm$ 1.0				
4	33 $\pm$ 4.1	29 $\pm$ 0.0	89	10 $\pm$ 0.4	100
10	92 $\pm$ 1.1	73 $\pm$ 1.3	80	18 $\pm$ 1.6	100
20	179 $\pm$ 4.1	132 $\pm$ 0.5	73	31 $\pm$ 1.1	90
40	269 $\pm$ 2.7	203 $\pm$ 2.6	75	42 $\pm$ 0.8	91
80	374 $\pm$ 8.0	289 $\pm$ 4.2	77	59 $\pm$ 4.1	93
160	622 $\pm$ 73.4	440 $\pm$ 39.1	71	80 $\pm$ 8.3	84

Solution $\text{NO}_3\text{-N}$ (mg/L)	$\text{NO}_3\text{-N}$ adsorbed (mg/kg char) [mean $\pm$ SE]	$\text{NO}_3\text{-N}$ Recovered in Extracts 1 and 2 ^A (mg/kg char) [mean $\pm$ SE]	Adsorbed $\text{NO}_3\text{-N}$ recovered in extracts 1 and 2 (%)	$\text{NO}_3\text{-N}$ Recovered in extract 3 ^A (mg/kg char) [mean $\pm$ SE]	Adsorbed $\text{NO}_3\text{-N}$ recovered in extracts 1, 2 and 3 (%)
40	129 $\pm$ 12.8	92 $\pm$ 0.8	71	11 $\pm$ 0.7	80

^AExtraction 1- 20 mL 0.01M CaCl_2 , Extraction 2 and 3- 20 mL 2M KCl.

The results of the biochar-soil equilibration study at 40 mg $\text{NH}_4\text{-N}$ /L (Figure 2) reveal that both biochar application rates (168t/ha and 335 t/ha) significantly ($p < 0.05$) increased the $\text{NH}_4\text{-N}$ sorption in both soil types. But the relative proportional increase in $\text{NH}_4\text{-N}$ adsorption compared to the soil only treatment was much greater in the sandy loam soil with a low ECEC than in the silty clay loam soil with a moderate ECEC. The 168 t/ha and 335 t/ha biochar applications increased the $\text{NH}_4\text{-N}$ adsorption in soil B (sandy loam) by 63 mg/kg (90% increase) and 104 mg/kg (149% increase). In contrast, the same biochar applications to soil A (silty clay loam) led to increases in $\text{NH}_4\text{-N}$ adsorption of 30 mg/kg (20%) and 60 mg/kg (40%).

Conclusion

This study has shown that greenwaste biochar increased the $\text{NH}_4\text{-N}$ retention capacity of soils by up to around 1 kg $\text{NH}_4\text{-N}$ / t of biochar, and that when applied in large quantities (up to hundreds of tonnes) it has potential to reduce losses of mineral N when in the $\text{NH}_4\text{-N}$ form prior to nitrification. This characteristic of the biochar may account for a significant proportion of the improvements in N fertiliser use efficiency noted in several studies. Our study has also demonstrated that the impact of biochar is greatest on light sandy soils with naturally low $\text{NH}_4\text{-N}$ retention properties, and that these soils should be targeted for biochar applications, in order to maximise the environmental and economic benefits from the biochar. Similarly weathered tropical soils with characteristically low CEC are likely to benefit greatly. The characterisation of biochar products should include $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ retention.

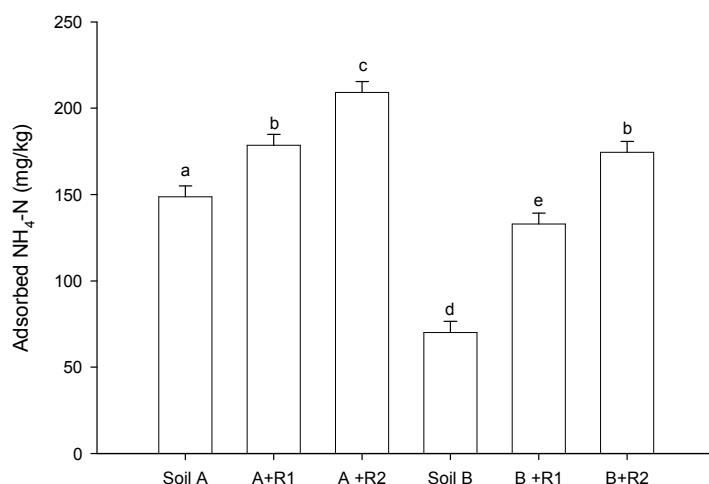


Figure 2. Mean $\text{NH}_4\text{-N}$ adsorbed by two fumigated soils mixed with greenwaste biochar following a 10h equilibration with a 40 mg/L $\text{NH}_4\text{-N}$ solution. Error bars are LSD at $p=0.05$. Different letters represent a significant difference between the treatments at $p<0.05$. [Soil A=Soil A (Silty clay loam) only; A+R1= Soil A + 168 t/ha biochar; A+R2=Soil A + 335 t/ha biochar; Soil B= Soil B (sandy loam) only; B+R1= Soil B + 168 t/ha; B+R2= Soil B + 335 t/ha biochar].

References

- Chan KY, van Zwieten L, Meszaros I, Downie A, Joseph S (2007) Agronomic values of greenwaste biochar as a soil amendment. *Australian Journal of Soil Research* **45**, 629-34
- Chan KY, van Zwieten L, Meszaros I, Downie A, Joseph S (2008) Using poultry litter biochars as soil amendments. *Australian Journal of Soil Research* **46**, 437-444.
- Glaser B, Haumaier L, Guggenberger G, Zech W (2001) The terra preta phenomenon: a model for sustainable agriculture in the humid Tropics. *Die Naturwissenschaften* **88**, 37-41.
- Lehmann J and Joseph S (2009) Biochar for environmental management: An introduction. In 'Biochar for Environmental Management' (Eds J Lehmann, S Joseph) pp. 1-12. (Earthscan: Sterling, USA).
- Lehmann J, Gaunt J, Rondon M (2006) Biochar sequestration in terrestrial ecosystems- a review. *Mitigation and Adaptation Strategies for Global Change*. **11**, 403-427.
- Sharpley AN, Kleinman PJA, Weld JL (2008) Environmental soil phosphorus indices. In 'Soil sampling and methods of analysis' (Eds MR Carter, EG Gregorich) pp.141-159. (CRC Press: Boca Raton, USA).
- Vance ED, Brookes PC, Jenkinson DS (1987) An extraction method for measuring soil microbial biomass C. *Soil Biol Biochem* **19**, 703-707
- van Zwieten L, Kimber S, Morris S, Chan KY, Downie A, Rust J, Joseph S, Cowie A (2010) Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. *Plant Soil* **327**, 235-246.

Growth of tongkat ali (*Eurycoma longifolia*) on a sandy beach ridges soil in Malaysia

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Abstract

Soils of sandy dunes or beach ridges interspersed swales (BRIS) are common in the coastal parts of the east coast in Peninsular Malaysia. The soils have low productivity due to many physical and chemical limitations. A planting trial of tongkat ali (*Eurycoma longifolia*), a medicinal plant sought after for its commercial value, was carried out on a BRIS soil in Setiu, Terengganu. Three levels of nitrogen with basal phosphorus (P) and potassium (K) were applied with and without organic mulch. Results showed significant positive effects of fertilizer input on plant height and root biomass yield, and fertilizer use efficiency improved with organic mulch. The optimum rate of fertilizer on this soil required by tongkat ali was 75 kg N/ha as urea with basal applications of P and K preferably in the form of organic mulch.

Key Words

BRIS soil, *Eurycoma longifolia*, fertilization, organic mulch, root biomass.

Introduction

One of the most sought after herbal plants for commercial exploitation in Malaysia is tongkat ali, scientifically known as *Eurycoma longifolia*. The medicinal properties of tongkat ali have been known for centuries (Ang *et al.* 2003; Kuo *et al.* 2004). Every part of the plant, especially the roots, is used for among others as an afterbirth tonic, reducing fevers, curing mouth ulcers and to treat intestinal worms. The roots contain quassinoids which are effective for eliminating malarial parasites. Despite these therapeutic properties, however, tongkat ali is more highly regarded for its purported aphrodisiac properties (Ang *et al.* 2003). This has led to the excessive gathering of the plant from its natural habitat by over-enthusiastic collectors.

It is common that in the virgin forests, tongkat ali grows tall reaching the forest canopy but flowering is infrequent. Thus regeneration of new plants is slow. As the demand for tongkat ali roots increase, the plant is becoming extinct and is scarcely available on the forest fringe. One has to go deep into the forest area to find wild tongkat ali. Domestication and commercial planting of this plant are very timely to support the local market demand.

Soils of beach ridges interspersed swales (BRIS) dominate large parts of the coastal areas of the east coast of Peninsular Malaysia. The soils have > 98% sand, with many associated limitations such as excessive drainage, high surface soil temperature, low moisture and low nutrient content. One way to green the site is to utilize the land for agroforestry planting, and tongkat ali is one of the medicinal plants selected for interplanting between forest trees. Thus, a fertilizer response experiment was carried out to assess application of different levels of urea on the root growth of tongkat ali and to study the effect of incorporating a mulch mat on the efficiency of applied urea.

Methods

Study site

The experiment was conducted in Setiu, Terengganu on a BRIS soil. The area was flat land formerly occupied by coastal shrubs and was cleared off before planting. The texture of the soil was highly sandy with more than 98% sand. Nutrient content was poor with average of 0.07% N, 0.86 µg/g P (Bray and Kurtz no. 2 method) and 0.05 cmol⁺ / kg exchangeable K in the top 5 cm layer soil; and 0.03%, 0.31 µg/g and 0.02 cmol⁺ / kg of N, P and K respectively for the 5-15 cm soil layer. During the dry period, the high air and surface soil temperatures can cause leaf scorching and wilting of the plant (Amir 1999).

Experimental layout

Seven treatments including the control were established to evaluate the effects of fertilizer and a combination

of mulch mat with fertilizer on the growth and root biomass yield of tongkat ali. The mulch mat, which was produced from oil palm empty fruit bunches fibres, was obtained from the nearby factory. Details of the treatments are depicted in Table 1. Treatment with mulch mat alone was not established as the number of mulch mat available was insufficient and the experiment focused more on testing the efficiency of urea granular fertilizer. Fertilizers were applied at 6-monthly intervals, with the first application was 2 weeks after planting. A mixture of mineral soil and palm fibres was added into each planting hole to improve water holding capacity for initial plant establishment. Planting stock of uniform size was obtained from the Kesedar site office in Kuala Krai, Kelantan. The experimental layout was a complete randomized block design with four replicates and 18 measured plants in each plot. Height growth measurement was recorded at 3-monthly intervals. When the stand was 2 years old, three representative plants of average growth from each plot were destructively sampled to measure their biomass yield. All data collected were analysed statistically based on Analysis of Variance and Duncan's Multiple Range Test.

Table 1. Fertilizer treatments for young tongkat ali plants on BRIS soil in Setiu, Terengganu, Peninsular Malaysia.

Treatment	Fertilizer rate
T1	Control
T2	50 kg/ha urea (+P, K)*
T3	75 kg/ha urea (+P, K)*
T4	100 kg/ha urea (+P, K)*
T5	50 kg/ha urea + EFB mulch mat (initial)
T6	75 kg/ha urea + EFB mulch mat (initial)
T7	100 kg/ha urea + EFB mulch mat (initial)

* P and K rates were at equivalent amount as available in mulch mat

Results

Growth of tongkat ali seedlings on BRIS soil were rather slow compared to that reported for other sites (Then 2008), but still differences were obvious between different rates of fertilizer application (Figure 1). At 2 months after planting, growth was the same regardless of the treatments. Differences in growth were only obvious after 5 months but the lowest was recorded with treatment T7 where the highest rate of urea was applied in combination with organic mulch mat. No significant differences were observed between fertilized and non fertilized plants. At stand age of 9-month-old, a similar trend was recorded with control treatment as good as fertilized plants. However, mulching showed significant improvement in plant height growth, and application of 50 kg/ha urea-N gave the highest height increment. The mulching effect was more obvious at one-year, when treatment T5 gave the highest height increment. The overall data showed that with mulching, 50 kg N/ha is sufficient whereas without mulching, tongkat ali requires more than 100 kg N/ha for one year growth period. Urea fertilizer has been proven to perform better with organic input (Ram *et al.* 2003, Vanlauwe *et al.* 2001).

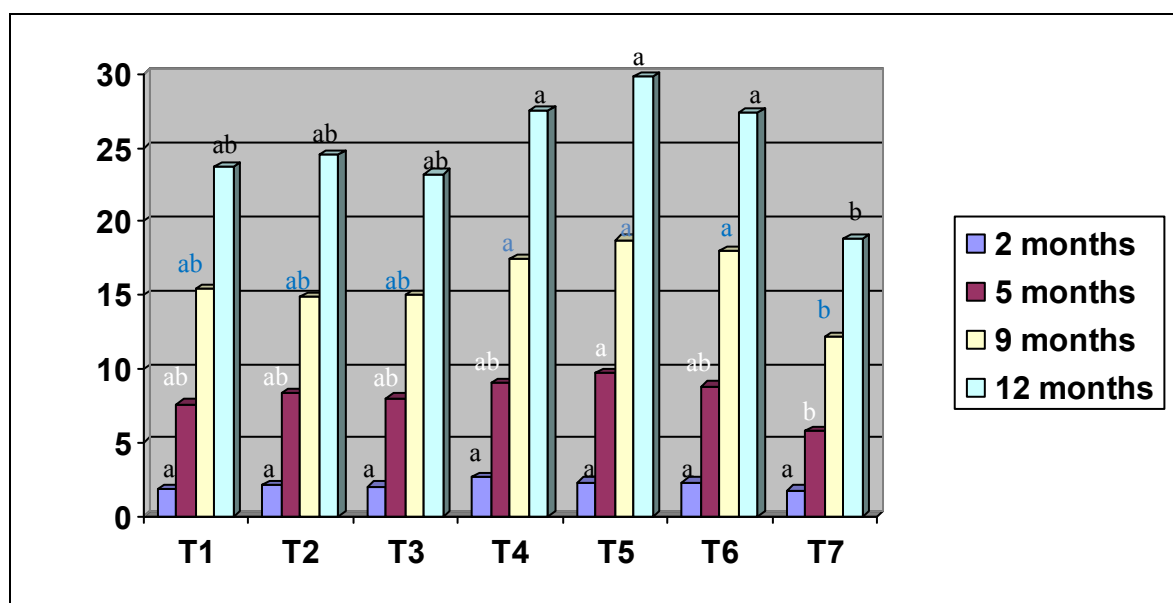


Figure 1. Cumulative height growth increment (cm) of tongkat ali plants in Setiu, Terengganu, Peninsular Malaysia. Means with the same letter across the treatments within the age group are not significantly different at $P < 0.05$.

Root biomass data do not conform well with height data. Figure 2 shows that highest root biomass yield was obtained with application of 75 kg N/ha in combination with organic mulch mat. The second highest was achieved with the same amount of N in combination with inorganic P and K sources. It seems that the optimum rate of fertilizer for root biomass production of tongkat ali on BRIS soil was 75 kg N/ha with balance P and K input, preferably using organic mulch. Application of 80 kg N/ha as urea was found to be optimum for tobacco planted on BRIS soil (Wan Azman *et al.* 1994). Wan Asma *et al.* (2000) also observed significant increment in biomass yield of serai wangi (*Cymbopogon nardus*), a medicinal shrub planted for its essential oils, when mulched with oil palm empty fruit bunch fibres.

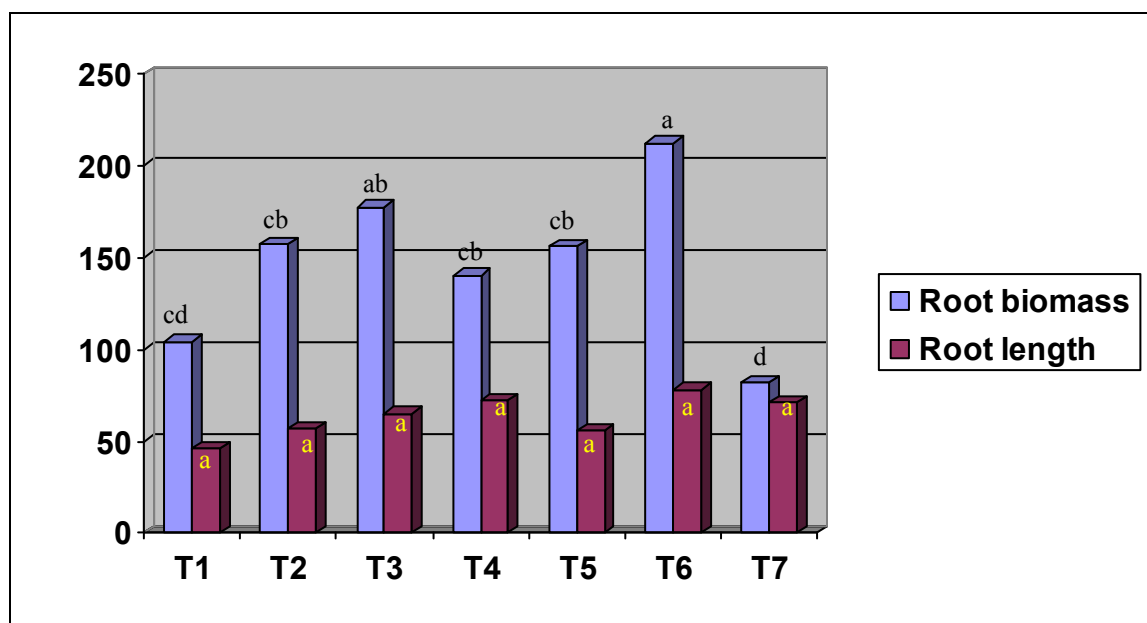


Figure 2. Root dry biomass yield (g) and length of tap root (cm) of 2-year-old tongkat ali plants as affected by fertilizer and organic mulch application in Setiu, Terengganu, Peninsular Malaysia. Means with the same letter across the treatments within the same variable are not significantly different at $P < 0.05$.

There was no significant difference between treatments in tap root length. Root form influences harvesting activity, with shorter roots of bigger diameter easier to pull out.

Conclusion

Tongkat ali can be cultivated on BRIS soil but its growth was slower than on better textures soils. Even

though this soil is excessively drained, application of fertilizer N source as urea significantly improved growth of tongkat ali and fertilizer efficiency was further improved when applied together with organic mulch. Root harvesting was much easier on the sandy soil.

Acknowledgement

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References

- Amir HMS (1999) Manual on the Reforestation with Selected Fast Growing Forest Species on BRIS Soils in Setiu, Terengganu, Peninsular Malaysia. Forest Research Institute Malaysia, Kuala Lumpur.
- Ang HH, Ngai TH, Tan TH (2003) Effects of *Eurycoma longifolia* Jack on sexual qualities in middle aged male rats. *Phytomedicine* **10**, 590-593.
- Kuo PC, Damu AG, Lee KH, Wu TS (2004) Cytotoxic and antimalarial constituents from the roots of *Eurycoma longifolia*. *Bioorganic and Medicinal Chemistry* **12**, 537-544.
- Ram M, Ram D, Roy SK (2003) Influence of an organic mulching on fertilizer nitrogen use efficiency and herb and essential oil yields in geranium (*Pelargonium graveolens*). *Bioresource Technology* **87**, 273-278.
- Then KH (2008) Growth performance of tongkat ali (*Eurycoma longifolia* Jack) intercropped with sentang and estimated root biomass production. In 'Plant, Health and Man - Past, Present and Future' (Eds YS Chang *et al.*) pp. 62-68. (Forest Research Institute Malaysia: Kuala Lumpur).
- Vanlauwe B, Aihou K, Aman S, Iwuafor ENO, Tossah BK, Diels J, Sanginga N, Lyasse O, Merckx R, Deckers J (2001) Maize Yield as Affected by Organic Inputs and Urea in the West African Moist Savanna. *Agronomy Journal* **93**, 1191-1199.
- Wan Asma I, Wan Rasidah K, Khozirah S, Rozita A, Abu Said A (2000) Utilization of oil palm empty fruit bunches for growing plants on BRIS soil: a preliminary study. In 'Utilization of Oil Palm Tree. Oil Palm Biomass: Opportunities and Challenges in Commercial Exploitation'. (Eds I Wan Asma *et al.*) pp. 223-230. (Oil Palm Tree Utilization Committee: Kuala Lumpur).
- Wan Azman WI, Aziz B, Salbiah H (1994) Influence of soil types on the performance of tobacco as affected by rates and sources of nitrogen fertilizer. In 'Proceedings of the International Conference on Fertilizer Usage in the Tropics' (Eds B Aziz *et al.*) pp. 148-154. (Malaysian Society of Soil Science: Kuala Lumpur).

How farmers' observations may assist in scientific research

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Abstract

Accepted modern farming practises with observed outcomes such as steadily increasing animal numbers, high utilisation of pastures, and heavier use of fertiliser nitrogen often appear at odds with farmers' notions of a healthy farming enterprise. An increasing number of farmers are not only questioning the accepted outcomes, but also implementing practises that are aligned to biological farming principles. The farmers observe the direct link between soil, plant, animal, and human health, and believe that soil health is the basis of high quality food production. Following the implementation of alternative soil fertility programmes these farmers have observed many benefits and significant changes e.g. increase in clover number and decrease in soil compaction, within the first year. However, scientist input is essential to ensure that these changes are not short term and at the expense of long-term production. Understanding of the reasons for these beneficial changes is also important to remove confusion and encourage rapid implementation of practises that help achieve the goal of sustainable farming. Typically these farmers are experienced owner operators highly skilled in observing and recording changes. They are by nature inquisitive and often good communicators keen to share their experiences. By forging a close link with these experienced farmers and scientists, the interchange of knowledge and observed changes in practical farming situations can be enhanced.

Key Words

Biological farming, grazed pastures, nitrogen fertiliser, water quality, soil health.

Introduction

In recent years, water quantity and quality have become important issues in many countries including New Zealand. The increased use of synthetic fertilisers, such as urea, has not only been expensive to farming systems, but also been considered as one of the causes of water quality degradation (Magesan *et al.* 1996; Monaghan *et al.* 2007). In the Central North Island (CNI), New Zealand, nutrient leaching is one of the risks to the continuation of farming. New Zealand farming needs solutions to nutrient leaching that are simple to implement and simple to monitor.

The Rotorua Lakes and Land Trust (RLLT) – a joint venture between Te Arawa Federation of Maori Authorities and Rotorua/Taupo Province of Federated Farmers – has been looking at various solutions to farm nutrient loss. One of the options is to modify soil biology by using the Eco-logic method to increase soil biota and root depth to capture nutrients, particularly N. This method is currently used by some mainstream farmers on a number of CNI farms. Instead of applying fertiliser nitrogen, a mix of dolomite (Ca & Mg) or lime (Ca), humate and soft carbon inoculated with specifically selected soil friendly fungi and bacteria is applied to improve soil health and speed nutrient cycling. Application of such essential elements is important for intensive pastures, especially for clover.

	Clover % in pasture	
	properties (6) with DoloZest & CalciZest	properties (6) without DoloZest & CalciZest
September	20%	11%
October	24%	12%
November	31%	12%
December	35%	18%

Clover plays an important role in pastoral New Zealand (e.g. Ledgard 2001). Clovers are able to provide sufficient nitrogen for high producing intensive dairy farming. More clover grown means: higher total milk, meat, and wool yields; less nitrogen fertiliser required; and lower overall costs. Essential elements can also provide benefits such as reduction in metabolic disorders.

Farmers' observations

The Rotorua Lakes and Land Trust is aware of a number of farms (dairy, deer and sheep farms) on different soil and climatic conditions that have been following this method for over 5 years. Some of these farms are intensively monitored by farmers. They use cages for biomass production, soil penetrometers for soil compaction, and refractometers to measure brix (sugar) levels in pastures. In general these farms have increased their farm pastoral production levels, noted considerable increases in root mass and importantly, experienced major savings on their conventional fertiliser costs (70-90% drop in urea use).

Other observations include:

- Reduction in soil compaction and soils are noticeably softer to walk on.
- Decrease in bare patches of soil.
- Increase in the percentage of clover in the sward – with bigger leafed and longer stemmed clover plants.
- Decrease in fertility patches in paddocks – i.e. more even growth between the front and back of paddocks.
- Stronger and more persistent growth of grass and clover under trees and fence lines.
- A change in grazing behaviour takes place with animals grazing immediately on entering a new break or paddock.
- Decrease in the damage caused by grass grub, black and brown beetle, and clover flea.
- Faster reincorporation of dung into the pasture soil - often almost completely within three weeks.

The common and accepted practise is that it is the scientists who will do research under laboratory and field conditions, and then give the information to farmers as knowledge sharing. However, in this study scientists need to do research based on farmers' observations to verify the results and also to explore the reasons for positive changes in the soil, plant and animal health.

Aims and objectives of this project:

This project aims to provide an innovative and environmentally sustainable solution to building deeper root zones and improved top soils for New Zealand pastures. It is based on the premise that increasing bacteria and fungi increases the soil microbial activity and in turn, topsoil development and which may reduce farm nutrient leaching.

Methods

This project is requested by farmers, directed by farmers, for the benefit of farmers. RLLT has approached Scion (Crown Research Institute) to help with scientific research to verify farmers' observations.

General survey

A survey of farms that are currently under biological farming principles will be conducted. The questionnaire to the farmers will include information regarding area of the farm, type of farming, how long they have been using this system, reasons for switching from conventional to present system, fertiliser usage history, any monitoring programmes, their observations on soil, plant and animal health, and possibly on their savings. Farmers' observations will give enough background information for the research.

Experimental sites

We aim to establish field experiments at five sites with different management regimes (e.g. dairy and sheep) with different soil and rainfall, which are already under conventional and biological farming. However, if such sites are not available, we will set up some experimental sites to study these farming systems. Fertiliser application will be similar to normal farming practices.

The field trials are expected to answer a number of queries including the role of the "smart fertiliser" product in increasing the soil biota and rooting depth; amounts of N uptake – improvement in productivity, brix (sugar) levels; any change in urine N; and amount of N leaching from soil under two contrasting farming systems.

A statistician will be used for an overview of the methodology to ensure adequate replication, number of samples, data analysis and accurate interpretation. Scion scientists will work to ensure that data collection, sample storage and analysis are consistent with the protocols required to maintain the project, and that the knowledge gained is disseminated as widely as possible.

N leaching will be monitored for a period of at least three years. This will give robust and practical time series data on nitrate leaching. Monitoring over time will allow understanding of different seasonal effects, and impacts of extreme climate events (intense rain) etc. We will install at least 15 suction cup samplers below rooting depth on each treatment site to collect soil water. The samples will be collected monthly, and in some cases after heavy rainfall events, to measure N concentrations at Veritec, an analytical laboratory within Scion. We will set up rainfall gauges at the experimental sites to measure precipitation. It is expected that the field experiment would take three years to complete.

Information dissemination and sharing

Information will be shared with farmers, Maori landowners and incorporations (e.g. Te Arawa FOMA), local and central government agencies, research providers and the general public. The results will be used for implementing new fertiliser regimes to save costs, and increase sustainable biomass production by farmers. A number of steps will be taken to make sure that the information is made available to the target audience through a range of communication and evaluation methods. These include: farmer newspapers, internet links, radio, farmer field days, and land use focus group meetings.

Expected benefits

This project is expected to provide a range of economic and environmental benefits to New Zealand farmers and the country. This project is expected to: increase farm productivity by reducing the reliance on costly conventional fertiliser systems that can be harmful to the environment; reduce nitrogen leaching into waterways by building deeper root zones; increase the scientific knowledge and understanding of biological farming systems and their potential impacts on farm productivity.

Conclusion

Farmers using alternative systems have observed positive changes to soil, plant and animal health and have made savings in fertilizer costs without losses in productivity. This has given an opportunity for the scientists to explore the reasons for such changes.

References

- Ledgard SF (2001) Nitrogen cycling in low input legume-based agriculture, with emphasis on legume/grass pastures. *Plant and Soil* **228**, 43-59.
- Magesan GN, White RE, Scotter DR (1996). Nitrate leaching from a drained, sheep-grazed pasture. I. Experimental results and environmental implications. *Australian Journal of Soil Research* **34**, 55-67.
- Monaghan RM., Hedley MJ, Di HJ, McDowell RW, Cameron KC, Ledgard SF (2007) Nutrient management in New Zealand pastures - Recent developments and future issues. *New Zealand Journal of Agricultural Research* **50**, 181-201.

Implications of minimum till dryland cropping systems for diagnostic P and K soil tests

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Abstract

Dryland broadacre cropping systems on Vertosols in northern Australia are presenting challenges to diagnostic soil testing methodologies. Because water availability is often limited in the surface soil during the growing season, the P and K status of the 0.10-0.30 m layer needs to be assessed to determine the likely availability of these nutrients to meet crop growth requirements, especially during peak growth periods pre- and post-anthesis. Furthermore, the widely adopted commercial soil tests do not appear to be appropriate to assess the P or K status of these soils because they are not correlated with the slow release nutrient pools (i.e. with acid-extractable P or tetraphenyl borate-extractable K). Re-assessments of soil sampling depth and soil P and K tests are necessary to develop diagnostic tools that are applicable to these soils and cropping systems.

Key Words

Soil sampling depth, Vertosols.

Introduction

Stubble retained systems are becoming the norm for broadacre grain cropping in the subtropics and dry tropics of northern Australia. This is because minimum or zero tillage systems improve water use efficiency by reducing runoff and erosion and effectively store subsoil moisture for subsequent use by the crop.

Minimum or zero tillage contrasts to the conventional tillage practices under which P and K soil tests were calibrated against grain yield in the 1970s and 1980s to serve as diagnostic indicators of the need for fertilisers. Conventional tillage regularly re-distributed nutrients through the plough zone and diagnostic soil samples were taken from 0-0.10 m to assess soil nutrient status. It is likely that with continued minimum or zero tillage systems, nutrient stratification will occur in the surface few centimetres, and the availability of these nutrients to the crop is then dependent on this zone retaining sufficient plant available water to allow active root growth. Modelling of plant available water during the growing season using long term weather data indicates that the 0-0.15 m soil layer is drier than the lower limit for 14-51% of the post-anthesis sorghum period and 17-65% of the post-anthesis wheat period. Similar regional variability is evident in the pre-anthesis period for both crop seasons, but soil moisture status is higher. These results indicate that, following establishment, the crop is likely to be dependent on soil nutrient reserves below 0.10 m for a substantial proportion of the growing season. This observation is supported by soil P data from a Vertosol at Colonsay in south-eastern Queensland following prolonged dryland cropping (Wang *et al.* 2007). Without P fertiliser addition, continuous cropping caused a decline of 55%, 35% and 10% in total P from the 0-0.10, 0.10-0.30 and 0.30-0.60 m layers respectively, compared to an uncropped reference soil.

For broadacre, dryland grain cropping, the Colwell (1963) soil test (0.5 M NaHCO₃ extractant; soil:extractant 1:100; extraction period 17 h) is generally used as a diagnostic soil test to determine whether or not soil P is adequate (Moody and Bolland 1999). However, at the Colonsay site, sequential extraction of the soil P with a range of extractants (Guppy *et al.* 2000) indicated that the greatest decrease in soil P in the 0.10-0.30 m layer due to cropping occurred in the M HCl extractable fraction, not the bicarbonate extractable fraction. These results raise doubts about the efficacy of the Colwell soil test to adequately reflect the availability of subsurface P under conditions where acid-extractable P is making a large contribution to available P. A similar situation applies to the assessment of K availability. While exchangeable K is generally used to identify K-responsive soils, K-depletion glasshouse experiments indicated that the amounts

of K taken up by successive crops growing in Vertosols were better correlated with changes in tetra-phenyl borate extractable K (TB-K) than changes in exchangeable K (Moody and Bell 2006). Available soil K reserves are therefore not being assessed by the exchangeable K method.

In dryland wheat, P supply prior to anthesis sets yield potential, but realisation of this yield is dependent on the crop accessing further P after anthesis (Fischer 1979). Given that the above findings indicate a major source of this post-anthesis P (and probably K) supply is obtained from deeper than 0.10 m, it is apparent that basing soil fertility assessment solely on the 0-0.10 m layer is questionable. Also questionable is the usefulness of a bicarbonate soil test for assessing available P when acid-extractable P appears to be a major source. Likewise, exchangeable K may not be the appropriate diagnostic soil test in soils such as Vertosols which often have considerable TB-K reserves.

This paper presents data on the stratification of P and K in grain cropping soils of northern Australia and the relationship between Colwell-P and acid extractable P and between exchangeable K and TB-K in these soils. The implications of these data for diagnosing the need for P and K fertilisers is discussed with reference to an appropriate soil sampling depth and an appropriate soil test.

Methods

Soil sampling and analyses

Soil samples (0-0.10 m or 0-0.15 m) were collected from 169 sites from the northern grains region of Australia which occupies approximately 4 Mha across northern New South Wales, southern and central Queensland. The soils comprise Vertosols, Chromosols and Sodosols (Isbell 1996). Soils were analysed for Colwell-extractable P, acid-extractable P (0.005 M H₂SO₄), and M NH₄Cl exchangeable K (Methods 9B2, 9G2 and 15A1, respectively: Rayment and Higginson 1992). Tetra-phenyl borate extractable K was determined using the method of Carey *et al.* (2000) with a 1 h extraction period. In addition, 15 cropped and uncropped paired sites on Vertosols were identified in this suite and 0.10-0.30 m samples from these sites also analysed by the above methods.

Stratification Index

A stratification index for Colwell-P, Acid-P and exchangeable K was calculated as the soil test value (0-0.10 m)/ soil test value (0.10-0.30 m).

Results and Discussion

Nutrient stratification

Colwell-P, Acid-P and exchangeable K were all stratified, with Colwell-P showing the greatest tendency for this (Table 1).

Table 1. Stratification index [value (0-0.10 m)/value (0.10 m-0.30 m)] for extractable P and K in some Vertosols of northern Australia.

	<i>Median</i>	Range
Colwell-P (mg/kg)	2.5	1.7-5.0
Acid-P (mg/kg)	1.6	1.0-4.0
Exchangeable K (cmol(+)/kg)	2.1	1.3-3.3

The pronounced stratification confirms that P and K tend to accumulate in the surface 0.10 m, presumably as a result of nutrients being cycled by the plant via subsoil absorption to deposition on the soil surface as plant residues. The 0-0.10 m layer is the standard soil sampling depth used to assess soil P and K sufficiency in the grains industry. It is apparent that analysing this soil layer would generally over-estimate the available P and K content of deeper soil layers, yet it is these layers that are likely to be a major source of available nutrient to the crop during significant proportions of cropping seasons.

The importance of subsurface P and K supply to dryland cropping of these soils has implications for fertiliser placement. While starter P (and K) fertiliser application at sowing will assist the crop to rapidly develop a root system, it is likely that this nutrient source will become inaccessible when the surface soil dries out. Complementary deeper application of fertiliser will also be necessary when P and/or K status of the subsoil is not sufficient to meet crop demands. Yield responses to deep fertiliser application have been obtained by Singh *et al.* (2005) in this environment.

Correlation between soil tests

Across both sampling depths there was no correlation between Colwell-P and Acid-P ($r = 0.35$; $P > 0.10$). This lack of correlation is highlighted by the Acid-P to Colwell-P ratio in the 0.01-0.30 m layer ranging from 1.5 to 82.5. Some of the soils had large amounts of Acid-P despite Colwell-P values being rated as very low. For example one soil from Clermont had 6 mg/kg Colwell-P and 495 mg/kg Acid-P in the 0.10-0.30 m layer. Data cited above from the Colonsay site show that acid extractable P is plant available, so although the Colwell-P value for the Clermont site suggests that site might be P-deficient in the subsoil, the Acid-P indicates a contrary conclusion.

There was no correlation between exchangeable K and 'apparent slow release K' (calculated as TB-K minus exchangeable K) and some soils had 4 times more slow release K than exchangeable K (Figure 1). Therefore, for both P and K, the current diagnostic soil test does not give an indication of nutrient reserves; nor can it be used to estimate the reserves.

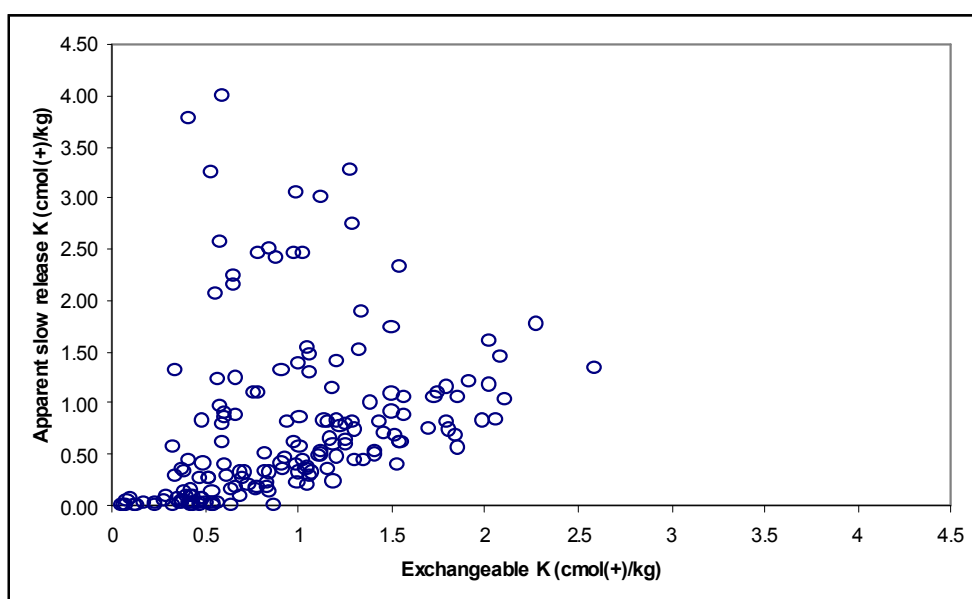


Figure 1. Variation in exchangeable K and apparent slow release K for soils of the northern grains region.

Conclusion

Dryland broadacre cropping systems on Vertosols in northern Australia are presenting challenges to diagnostic soil testing methodologies. It is apparent that the P and K status of the 0.10-0.30 m layer needs to be assessed to determine the likely availability of these nutrients to the crop post-anthesis. Furthermore, the widely adopted Colwell-P and exchangeable K soil tests do not appear to be appropriate to assess the P or K status of these soils because they are not correlated with the slow release P and K pools in these soils. Re-assessments of soil sampling depth and soil P and K tests are necessary to develop diagnostic tools that are applicable to these soils and these cropping systems.

References

- Carey PL, Metherill AK, Huen CG, Almond C (2000) Using an improved tetra-phenyl boron K method to measure Westland soil K reserves. In 'Soil research: A knowledge industry for land-based exporters.' Occasional Report No. 13. (Eds LD Currie, P Longanathan) pp 247-257. (Fertilizer and Lime Research Centre, Massey University: Palmerston North, New Zealand)
- Colwell JD (1963) The estimation of phosphorus fertilizer requirement of wheat in southern New South Wales. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 190-197.
- Fischer RA (1979) Growth and water limitation to dryland wheat yield in Australia; a physiological framework. *Journal of the Australian Institute of Agricultural Science* **45**, 83-94.
- Guppy CN, Menzies NW, Moody PW, Compton BL, Blamey FPC (2000) A simplified sequential sampling phosphorus fractionation method. *Communications in Soil Science and Plant Analysis* **31**, 1981-1991.
- Isbell RF (1996) 'The Australian Soil Classification.' (CSIRO Publishing: Melbourne)

- Moody PW, Bell MJ (2006) Availability of soil potassium and diagnostic soil tests. *Australian Journal of Soil Research* **44**, 265-275.
- Moody PW, Bolland MDA (1999) Phosphorus. In 'Soil analysis: an interpretation manual'. (Eds KI Peverill, LA Sparrow, DJ Reuter) pp. 187-220. (CSIRO Publishing: Melbourne)
- Rayment GE, Higginson FR (1992) 'Australian Laboratory Handbook of Soil and Water Chemical Methods' (Inkata Press: Melbourne)
- Singh DK, Sale PWG, Routley RR (2005) Increasing phosphorus supply in subsurface soil in northern Australia: Rationale for deep placement and the effects with various crops. *Plant and Soil* **269**, 35-44.
- Wang X, Lester DW, Guppy CN, Lockwood PV, Tang C (2007) Changes in phosphorus fractions at various soil depths following long-term P fertiliser application on a Black Vertosol from south-eastern Queensland. *Australian Journal of Soil Research* **45**, 524-532.

Influence of sewage sludge application in the recovery of a degraded quartzpissament

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Abstract

Degraded areas are sites that have reduced or lost potential soil capacity, generally caused by unsustainable anthropic exploitation, and therefore the use of organic materials for the recovery of these areas is extremely important. This study aimed to evaluate the efficiency of sewage sludge for the recovery of a quartzpissament which had been degraded by the loss of the superficial layer and high compaction level. The experiment had random block design, 8 treatments and 4 replications. The treatments were: absolute witness (control without sewage sludge and without mineral fertilizer); mineral fertilization, according to calculations for needed doses of N, P and K; supplementation with K; 2.5 Mg/ha of sewage sludge (dry base)+ supplementation with K; 5 Mg/ha of sewage sludge (dry base)+ supplementation with K; 10 Mg/ha of sewage sludge (dry base)+ supplementation; 15 Mg/ha of sewage sludge (dry base)+ supplementation with K; and 20 Mg/ha of sewage sludge (dry base)+ supplementation with K. Sewage sludge was beneficial to the recovering soil regarding the significant increase in the main chemical characteristics, phosphorus, organic matter and CTC. The continued application of residue should be used as the recovery measure for the whole degraded area.

Key Words

Sewage sludge; soil fertility; degraded areas.

Introduction

Degraded areas have increased considerably, causing a lot of damage to the environment. They are characterized by the removal of the soil superficial horizon which results in loss of nutrients and organic matter, lack of biological activity and alteration of physical properties, facilitating erosive processes and substrate acidification (Marx *et al.* 1995).

The recovery process of these areas is slow and is related to the soil recovery capacity. Thus, several techniques have been used in order to recover degraded soils and most of them combine mechanical practices that aim to break off compacted layers, with the addition of organic matter (De Maria *et al.* 1999). Sewage sludge has widely been used as a conditioner and fertilizer to recover degraded areas (Brofas *et al.* 2000). Organic matter cycling and decomposition, difficult processes to start in degraded soils, occur quickly with the application of sewage sludge; and depending on the amount of remaining superficial soil, it is possible to significantly recover the soil within 3 to 5 years through an intensive management and use of organic materials that speed up plant growth and the processes of soil formation (Visser 1985).

Considering that degraded areas are areas that have been reduced or lost soil potential capacity, generally caused by unsustainable anthropic exploitation, and that the use of organic materials for the recovery of these areas is extremely important, this study aimed to evaluate the efficiency of sewage sludge from the Sewer Treatment Station of Jundiaí, SP, Brazil, for the recovery of a quartzpissament in a degraded area.

Material and methods

This experiment was carried out in the town of Itatinga-SP, Brazil, on one of the farms of Cia. Suzano Bahia Sul de Papel e Celulose, located in the geographical coordinates 23°06' S latitude 48°36' W longitude and average altitude of 845m. The region has annual average rainfall of 1.635 mm, temperature of 19.4°C and relative humidity of 83%. The predominant weather is Cwb according to Köppen classification.

The original soil is classified as sandy-texture quartzpissament, according to the Brazilian System of Soil Classification (EMBRAPA 2006). Previously, the area had been a lumber deposit, degraded because of the loss of superficial layer and high level of compaction.

Analysis results should that the soil had the following chemical characteristics before the experiment

installation: 4.4 pH (CaCl₂); 9 g/dm³ of organic matter; 4.3 mg/dm³ of P (resin); 23; 0.4; 4 and 1 mmol_c/dm³ of (H+Al), K⁺, Ca²⁺ and Mg²⁺, respectively; 12.6; 4.6; 27.6; 0.6 and 0.1 mg/dm³ of B, Cu, Fe, Mn and Zn, respectively, and 18% base saturation.

The experiment was installed in a random block design with 8 treatments and 4 replications, a total of 32 plots of 384 m², summing up 1.23 ha. The area of each plot had 49 plants of pioneer, secondary and climax species.

The treatments used in the experiment were: absolute witness, without sewage sludge and without mineral fertilizer; mineral fertilization, according to the needs of N, P and K; supplementation with K; 2.5 Mg/ha of sewage sludge (dry base) + supplementation with K; 5.0 Mg/ha of sewage sludge (dry base) + supplementation with K; 10.0 Mg/ha of sewage sludge (dry base) + supplementation with K; 15.0 Mg/ha of sewage sludge (dry base) + supplementation with K; 20.0 Mg/ha of sewage sludge (dry base) + supplementation with K. The treatment with mineral fertilization was the following one: 260 Kg/ha of the formulate 6-30-10 + 0.3% B at planting; 1.5 Kg/ha zinc sulfate, separately applied according to soil analysis and recommendation Gonçalves *et al.* (1996), was also added. The chemical fertilizers used in the formulate was: ammonium sulfate, simple superphosphate, potassium chloride and boric acid.

The sewage sludge that was used in the experiment came from the sewer treatment station in the city of Jundiaí, SP, Brazil, and had the following concentrations: 25; 16.6; 1.9; 12.2; 2.3; 19.2; 440 and 200 g/kg of N, P, K, Ca, Mg, S, O.M. and organic carbon, respectively; 850; 25.950; 584; 573; 0.1; 8.24; 162.7; 37.8 and 164.4 mg/kg of Cu, Fe, Mn, Zn, As, Cd, Cr, Ni and Pb, respectively, 55% of humidity; 8 C/N ratio; and 5.0 pH.

Liming was done only in the treatments that received chemical fertilization and supplementation with K by applying 1.09 Mg/ha of limestone (PRNT at 91%). The sewage sludge was spread mechanically on the surface and incorporated in the planting line.

The soil samples for analyses were collected at six, and twenty-four months after application, using a Dutch auger in the 0-20 cm layer, then they were air dried, sieved (2mm mesh), homogenized and submitted to chemical analysis. The compound samples were obtained from the mixture of simple samples collected in several points within each experimental plot for soil analysis after sewage sludge application. Soil analysis was done at the Laboratory of Soil Fertility of the School of Agronomical Sciences/UNESP, campus of Botucatu-SP, Brazil. The results were submitted to statistical analysis using software "SISVAR", version 4.2.

Results and discussion

The results of soil analysis at six months after the sewage sludge application showed increases in the values of pH and calcium and magnesium contents for treatments of mineral fertilization and supplementation with potassium (Table 1). Consequently, an increase in the values of base sum (BS) and V% was verified and that can be explained by the use of limestone in these treatments. Although the treatment with 20 Mg/ha of sewage sludge had not received limestone, it presented a Ca content equivalent to those treatments.

Table 1. Chemical analysis of the soil done six months after sewage sludge application to a degraded area.

Treatments	pH	M.O.	P _{resin}	Ca	Mg	K	SB	CTC	V%
				-----mmol _c /dm ³ -----					
Witness	4.3 b	13 b	4.7 bc	3 c	0.9 b	0.6	4.7 c	35 c	14 b
Mineral Fertilization	5.0 a	13 b	4.5 c	8 ab	5.8 a	0.6	14.6 a	37 bc	39 a
Supplementation with K	5.0 a	12 b	6.8 bc	9 ab	5.0 a	0.5	14.3 a	35 c	40 a
2.5 Mg/ha SS + K	4.2 b	18 ab	7.0 bc	4 bc	0.6 b	0.5	5.2 c	38 bc	14 b
5 Mg/ha SS + K	4.1 b	18 ab	9.7 bc	3 c	0.5 b	0.6	4.0 c	41 abc	10 b
10 Mg/ha SS + K	4.1 b	18 ab	12.2 abc	5 bc	0.6 b	0.5	5.7 bc	48 abc	12 b
15 Mg/ha SS + K	4.0 b	20 a	14.5 ab	5 bc	0.6 b	0.4	6.4 bc	52 ab	12 b
20 Mg/ha SS + K	4.1 b	20 a	23.5 a	10 a	1.0 b	0.7	11.4 bc	54 a	21 b
CV (%)	4.0	16.6	38.8	34.4	40-7	38.2	29.7	15.2	28.2

Means followed by the same letter in the column do not differ among themselves by Tukey's Test at 5%.

When compared to treatments with mineral fertilization and supplementation with P, pH decreased, corroborating the data obtained by Simonete *et al.* (2003). The addition of sewage sludge caused the increase in the soil organic matter when compared to the other treatments. The values for the plots that received the

highest dose of sewage sludge were 35% higher than the witness.

The high contents of organic matter in the sewage sludge contributed to the increase of soil CTC, and according to Colodro and Espindola (2006) the CTC increase allows a higher storage of cation elements, making it an important parameter in the evaluation of degraded soil recovery. The impact of soil quality, indicated by CTC, with the addition of sewage sludge, was evident by the addition of 13 (witness) to 54 mmol/dm³ for the highest dose of sludge during six months. However, the effect of treatments on the soil base saturation was not verified because the K and Mg contents present in the sludge are low.

A significant increase of P content in the soil was noticed with the use of sludge as 166, 249 and 332 kg/ha of P were added with doses of 10, 15 and 20 Mg/ha, respectively. According to Visser (1985), organic matter cycling and decomposition, difficult processes in degraded soils, occur rapidly with the application of sewage sludge, which can be proved by the obtained data in this experiment because there were significant increases of P and CTC contents in the soil after six months of the residue application in the soil. Melo *et al.* (1994) also observed a very short degradation time of the sewage sludge organic matter, when compared to other organic materials.

At twenty-four months after the sewage sludge application, reduction of the organic matter effects in the soil was verified and the values obtained in the treatments were close to the initial content (9 mg/dm³). These results influenced directly in the soil CTC that also reduced after 2 years of sewage sludge application.

The treatments that received mineral fertilization and supplementation with K provided the highest pH rates, highest base contents in the soil and, consequently, the highest base saturations, which were expected considering there is a positive correlation of pH in the soil with base saturation.

Sewage sludge continued influencing P contents in the soil and the highest values were verified in the highest applied doses of sludge. However, P contents in this period of time are lower than the ones obtained before the experiment installation, showing that new applications of the residue can be required. According to Visser (1985), it is possible that a significant soil recovery within 3 to 5 years through intensive management and use of organic materials that speed plant growth and the processes of soil formation; however, more frequent applications of organic matter are necessary because in sandy soil, the effects of organic matter had reduced greatly 2 years after application.

Table 1. Chemical analysis of the soil done twenty-four months after sewage sludge application in an degraded area.

Treatments	Twenty-four months after application									
	pH	M.O.	P _{resina}	P _{resina}	Ca	Mg	K	SB	CTC	V%
			√x+0,5	Orig.	-----mmol _e /dm ³ -----					
Witness	4.3 bc	9	1.2	0.5	2 b	0.6 b	0.4 b	3.2 c	30	11 b
Mineral Fertilization	4.6 ab	10	2.1	4.0	4 a	2.7 a	0.5 ab	7.3 a	32	23 a
Supplementation with K	4.8 a	11	1.5	1.5	4 a	1.9 a	0.5 ab	6.0 b	28	22 a
2.5 Mg/ha SS + K	4.3 bc	11	1.5	1.5	2 b	0.8 b	0.6 a	3.5 c	34	11 b
5 Mg/ha SS + K	4.2 c	11	1.5	1.3	2 b	0.6 b	0.5 ab	3.3 c	35	10 b
10 Mg/ha SS + K	4.2 c	10	1.5	1.5	2 b	0.7 b	0.4 b	3.4 c	34	10 b
15 Mg/ha SS + K	4.1 c	13	2.2	4.5	2 b	0.8 b	0.5 ab	3.5 c	36	10 b
20 Mg/ha SS + K	4.2 c	11	1.4	1.0	2 b	0.6 b	0.4 b	3.3 c	35	9 b
CV (%)	3.6	15.2	37.0	117.1	11.4	32.7	15.0	11.3	11.0	14.8

Means followed by the same letter in the column do not differ among themselves by Tukey's Test at 5%.

Conclusions

The sewage sludge provided an increment in soil quality in recovery, with significant increases in the main chemical characteristics phosphorus, organic matter and CTC.

Continued residue application is a recovery produce for the whole degraded area

Bibliography

- Brofas G, Michopoulos P, Alifragis D (2000) Sewage sludge as an amendment for calcareous bauxite mine spoils reclamation. *Journal of Environment Quality* **29**, 811-816.
- Colodro G; Espíndola CR (2006) Alterações na fertilidade de um latossolo degradado em resposta à aplicação de lodo de esgoto. *Acta Scientiarum* **28**(1) p.15.
- De Maria IC, Castro OM, Souza Dias H (1999) Atributos físicos do solo e crescimento radicular de soja em Latossolo Roxo sob diferentes métodos de preparo do solo. *Revista Brasileira de Ciência do solo*, **23**, 703-709.
- EMBRAPA (2006) Centro Nacional de Pesquisa de Solos-CNPS. Sistema brasileiro de classificação de solos. Brasília: Embrapa-SPI; Rio de Janeiro: Embrapa-CNPS, pp.306.
- Marx DH; Berry CR, Kormanik PP (1993) Application of municipal sewage sludge in forest and degraded land. In 'Agricultural utilization of urban and industrial byproducts: proceedings'. (Eds DL Karlen, RJ Wright, WD Kemper) pp.275-295. (The Soil Science Society of America and The American Society of Agronomy).
- Simonete MA, Kiehl JC, Andrade CA, Teixeira CFA (2003) Efeito do lodo de esgoto em um Argissolo e no crescimento e nutrição de milho. *Pesquisa Agropecuária Brasileira*, v. 38, n.0.
- Visser S (1985) Management of microbial process in surface mined land reclamation in western Canada. In 'Soil reclamation processes' (Eds RL TATE III, DA KLEIN) pp.204-241. (New York: Marcell Dekker).

Investigation on Soil Fertility and Citrus Yield in South China

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Abstract

The soil fertility and physical property were evaluated for some orchards of three main citrus species in southern China to understand the suitable soil types and fertility status required for high yield citrus production. Three groups of soil samples from high, medium and low yield orchards, and from 17 counties of 6 provinces were taken and tested respectively. Soil analysis result indicated that over 50% of the soils were low in organic matter (OM), pH, total N, P, K, available Mg, Si, B, and Zn. Higher citrus yields were found from the orchards with higher soil OM, pH, total N and P, available K, Ca, Mg, Si, Zn, Mo and slowly available K contents. But soil total K, available N, Mn and B didn't show significant relationship with citrus yields. More than 30% of the soils' available Al, Na, Fe and S levels were higher than the critical levels and brought negative effects on citrus yields. Soil available B and Zn were positively related to citrus yields, while soil Al negatively related to it. When soil pH was lower than 6.5, citrus yield showed a positive relationship with the increase of soil pH. Higher citrus yields were also found in soils with higher percentage of base saturation and proportion of small clay particles. Results also showed that base saturation and soil pH were less variable than other parameters.

Key Words

Citrus; Fertility; Nutrient; Critical index, Yield

Introduction

Citrus is grown world-wide with about 100 million tons yield per year. It is the largest fruit in southern China and its production plays an important role for local economic and poverty alleviation in mountainous regions. There were over 1.81 million ha of citrus planted in 18 provinces and 70% of them located in Hunan, Hubei, Sichuan, Jiangxi, Zhejiang and Guangdong provinces. Three major types of citrus-- Satsuma Mandarin (*C. unshiu*), Navel Orange (*C. sinensis* L.), and "Ponkan" Mandarin (*Citrus reticulata* Blanco) are planted on red soils in south China. Most of them planted on poor, marginal and newly reclaimed lands. Therefore, citrus yield was low (7,695 kg/ha) in the region, comparing with the world average of 14,190 kg/ha (He 1999). Lower yield is mainly caused by poor soil fertility and poor nutrient management. Inadequate nutrient management mainly due to producer lacks of information and knowledge of soil fertility. Therefore, fertilizers were not properly applied to match with citrus growth.

Soil testing is crucial for evaluating soil fertility and making fertilizing recommendations. Previous study mainly focused on a relatively small area and generally assessed one or two nutrient elements in China. Therefore, no report on the soil fertility status of citrus with large scale areas was found in the region. Research reports have confirmed that soil nutrient deficiencies of P, K, Mg, Zn, B, and Fe were widespread and they reduced citrus yield and quality (Li *et al.* 1997; Lu *et al.* 2001; 2002). Thus, discovering the critical limiting nutrients is essential for improving citrus nutrient management.

Materials and methods

A total of 63 soil samples were taken from the citrus orchards in 17 counties of 6 provinces during 2000 to 2001. In each county, soil samples were taken from 3-7 orchards with low (<22,500 kg/ha), medium (22,500 to 45,000 kg/ha) and high (>45,000 kg/ha) yields. Each soil sample was consisted of 20 sub-samples taken under the crown of citrus tree with depth of 30 cm. Soil pH, OM, nitrogen (N), phosphorus (P) and potassium (K), slowly available K, base-saturation percentage (S%), silicon (Si), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), aluminum (Al), iron (Fe), manganese (Mn), zinc (Zn), boron (B), molybdenum (Mo) and soil particle size were tested. All of the soil sample were analyzed by routine methods (Bao 2000). Criteria for the classification of citrus soil nutrient status were based on the reported common standards showed in Table 2 (Lu *et al.* 2002). Range, mean, standard deviation and coefficient of variance were calculated using Microsoft Excel (Microsoft, WA, USA) spread sheet.

Result and discussion

Soil pH and organic matter

Although citrus can be planted in soils with either a high or low pH, the optimal soil pH for citrus ranges from 5.5 to 6.5 (He 1999). We found that the soil pH in the region ranged from 3.9 to 8.9 and most were below 6.5. When the citrus orchards were grouped into high, medium and low yielding orchards, it was observed that the average soil pH in high and medium yielding orchards was above 5.9 while in low yielding orchards was 5.4. The percentages of acidic soils in the medium and low yielding orchards occupied 50% and 68%, while in high yielding orchards was 45%. Our results also indicated that citrus yields tend to increase with the increase of soil pH when they were below 6.5.

Soil OM is one of the most important soil fertility indicators and usually its content positively related to citrus yield. Our result showed that the average soil OM content was 15.6 g/kg (2-54.9 g/kg). The average soil OM content of high yielding orchards was 18.2 g/kg, while medium and low yielding orchards were below 16.2 g/kg (Table 1). Table 2 shows the modified classification standard for citrus based on traditional standards (Lu *et al.* 2002). According to the standard, over 50% of citrus soils were low (<15 g/kg) in OM.

Table 1. Average soil OM and macronutrient analysis results (g/kg, mg/kg)

Items	TN* g/kg	TP g/kg	TK g/kg	OM g/kg	AN mg/kg	AP mg/kg	AK mg/kg	SAK mg/kg
High yielding orchards (n=22)	1.5550	0.6400	14.979	18.181	89.996	22.436	156.19	344.00
Medium yielding orchards (n=22)	1.0668	0.5845	15.020	16.050	84.446	21.990	146.55	333.68
Low yielding orchards (n=19)	1.0747	0.5053	14.242	16.105	88.288	15.788	95.556	231.32

*TN= total N, TP= total P, TK= total K, AN= available N, AP= available P, AK= available K, SAK= slowly available K, OM=organic matter.

Soil nutrients

Soil analysis results showed that all the soil nutrients tend to decrease from the high yielding orchards to the low yielding orchards (Table 1). According to routine soil critical levels, the proportions of tested soils that lower than the suggested critical levels were: total N 92.1%, available N 67.8%, total P 66.7%, available P 60.2%, slowly available K 55.6% and available K 43.7% respectively. The unbalance of soil nutrients may be one of the major reasons for low yields.

Soil Ca, Mg, and Si levels tend to decrease from the high yielding orchards to the low yielding orchards. Sulphur, however, tend to be high in the low yielding orchard than in the high yielding orchards (Table 2). About half of the soils from high yielding orchards were low in Ca and Mg, while 36.4% and 68.4% of the soils were low in soil Ca in medium and low yielding orchards. Similarly, 68.2% of medium and 74.1% of low yielding orchards were rated as low in soil Mg. Up to now, we didn't find citrus soil standards for evaluating soil available S and Si. Our research suggested that S 35 mg/kg and Si 80 mg/kg could be considered as temporary critical levels. Based on these critical levels, the proportions of tested soils that below the critical levels were: soil Ca 48.6%, soil Mg 64.1%, and soil Si 79.4% respectively. For soil S, 36.5% of them were higher than 35 mg/kg.

Table 2. Soil base saturation percentage, second and micronutrient analysis result (mg/kg)

Nutrient	Si	Ca	Mg	S	Na	Al	Fe	Mn	Zn	B	Mo	BS%
High (n=22)	115.1	1973	186.2	33.09	42.03	133.5	22.85	30.75	1.46	0.373	0.147	92.8
Middle (n=22)	78.39	1777	129.7	37.46	45.23	128.3	33.82	26.11	1.32	0.334	0.130	87.9
Low (n=19)	43.44	1073	136.5	71.22	57.98	221.9	36.30	30.34	1.03	0.343	0.120	80.9

Soil analysis results also showed that available Zn, B and Mo were high and the available Na, Al and Fe were relatively low in high yielding orchards (Table 2). There was no significant difference on soil available Mn between high and low yielding orchards and it may not a yield limiting nutrient factor in the region. Our data recommend that 45 mg/kg and 130 mg/kg can be considered as temporary critical levels for soil available Na and Al. Result also showed that 25.7% of the soil Mn, 57.2% of the Zn, 85.9% of B, 16.1% of Mo, 20.9% of Fe, 34.9% of Na and 55.9% of Al were not in optimum ranges. This result indicated that B and Zn were the most important micronutrients and Al was the most important toxic soil element in the regions as well.

Soil base-saturation (BS%) and particle size distribution

Soil analysis result indicated that soil base saturation percentage was positively related to citrus yield. The

highest average soil base saturation (92.8%) was found in the high yielding orchards and lowest one (80.9%) was found in the low yielding orchards (Table 2). Result showed that 41.9% of the tested soils' base saturation was below 90%. This level could be temporary set as the critical level of soil base saturation for citrus.

Our result also showed that the small particle (<0.001mm) content was positively related to citrus yield. Clay contents of high yielding orchards were higher than those in the low yielding orchards (Table 3). In some low yielding orchards, the surface soil layer was quite thin (<30cm) with high proportion of gravel. Soil analysis showed that the percentages of large (0.05~ 0.01mm) to medium (0.005~ 0.001mm) particles were relatively stable (50.81~50.99%) in all the orchards. The proportion of small particles was much more variable compared with medium and large particles.

Table 3. Soil particle size distribution and proportion

Particle size (mm)	> 0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001
High yielding orchards (n=22)	7.15	16.36	24.43	12.18	14.20	25.68
Medium yielding orchards (n=22)	8.80	19.00	24.16	11.08	15.90	21.06
Low yielding orchards (n=18)	10.39	19.46	23.67	10.58	16.74	19.16

Conclusions

In the citrus orchards of China, low soil fertility was one of the major, if not the primary, factors limiting citrus yield. Our soil fertility investigation and soil analyses results indicated that over 60% of the soils were low in N, P, Mg, Si, and B, and over 50% of the soils were low in OM, pH, K, and Zn. We also found that the available Mn have no significant relationship with citrus yield. Those soils with high Al, Na and S showed lower fertility for citrus. Higher citrus yields were strongly associated with higher soil base saturation percentage and higher proportion of small soil particles.

Variability in soil base-saturation percentage and soil pH was smaller than other soil fertility parameters.

Variability in total N, P and K was smaller than the soil available N, P, K and other available nutrients. A strong positive relationship was found between soil OM and total N, available soil N, and soil Mg contents.

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References

- Bao Shidan (2000) Agro-chemical Analysis of Soil. Agricultural Publish House of China, Beijing.
- He T.F (1999) Mineral Nutrient of Citrus. Citrus. Agriculture Publish House of China, Beijing. 281-328.
- Li JS, Chen F, Lu ZG (1997) Effect of application Fe-chelate on citrus in Three Gorges Region. *Hubei Agriculture Science* **2**, 25-26.
- Lu JW, Chen F, Wan YF (2001) Effect of potassium on the yield and quality of navel orange. *Journal of Fruit Science* **18**(5), 272-275.
- Lu JW, Chen F, Wang FH (2002) Study of classification of the soil nutrient status of citrus orchard in Hubei province. *Plant Nutrition and Fertilizer Science* **8**(4), 390-394.

Is Sulfur Limiting Maize Grown on Eroded Midwestern U.S. Soils?

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Abstract

The importance of adequate sulfur (S) for maize (*Zea mays* L.) production has been recognized for many years and recently confirmed by positive yield responses. We compared a granular S-enhanced fertilizer material [SEF (13-33-0-15S)], granular ammonium sulfate [AMS (21-0-0-24S)], and liquid ammonium thiosulfate [ATS (12-0-0-26S)] on eroded Clarion (Typic Haplaquolls) hill slopes in central Iowa for three years. Applying 34 kg S/ha as SEF significantly ($P \leq 0.05$) increased mean V5 plant dry weight each year. AMS and ATS showed a similar but non-significant trend. Whole-plant S concentrations at V5 were generally higher than the control for all S sources. Grain yield and moisture content at harvest were not affected by S in 2006 and 2007. In 2008, 34 kg S/ha as SEF significantly increased yield by 0.76 Mg/ha. The agronomic efficiency of S (yield per unit applied) was greatest for SEF in 2006 and 2008 (12.3 and 22.5 kg grain (kg S)⁻¹, respectively). Below-normal precipitation during the 2006 and 2007 growing seasons and inherent soil variability presumably affected our S yield response, but overall we conclude that S may become a limiting nutrient for maize, especially if maize stover is harvested as a bio-energy feedstock.

Key Words

Sulfur fertilizer, maize, nutrient-use efficiency.

Introduction

Although S fertilization is not commonly recommended for maize production in the Midwestern U.S., the importance of adequate S has been recognized for many years (Hoeft *et al.* 1985). Recently, positive yield responses to S fertilizer have been documented (Stecker *et al.* 1995; Rehm 2005; Lang *et al.* 2006), but as in the past, responses have not been consistent. Responsive sites usually have coarse-textured soil, with relatively low organic matter, indicating that mineralization of organic S plays an important role in supplying S to crops. Under optimum soil temperature and moisture conditions, Tabatabai and Bremner (1972) showed that a significant amount of sulfate-S will be mineralized in a short period of time. However, when soils are cold in the early spring – a common occurrence in the upper Midwest – S mineralization will be reduced and plant-available sulfate levels will be lower (Rehm 2005). Furthermore, on eroded soils or where crop residues are being harvested, decreasing levels of organic matter can reduce the pool of available S, and thus increase the probability of a yield response to S fertilizer.

Once the need for S fertilizer is identified, selection of an appropriate source is the next management decision faced by growers, but few studies have been conducted to evaluate S sources. Based on limited data, maize yields following broadcast application of elemental S were no different from those receiving sulfate sources (Rehm 1984). Similarly, both fluid and dry S sources had an equal effect on maize yield (Rehm 2005), provided that seed contact was avoided. Our objective was to determine maize response to S fertilizer, using a granular S-enhanced material [SEF (13-33-0-15S)], granular ammonium sulfate [AMS (21-0-0-24S)], or liquid ammonium thiosulfate [ATS (12-0-0-26S)] on low organic matter, eroded hill slopes in central Iowa, USA.

Methods

Field plots were established during three consecutive years in central Iowa, USA, on Clarion (fine-loamy, mixed, mesic Typic Haplaquolls) loam (2006 and 2008) or silt loam (2007). The prior crop was soybean (*Glycine max* L. Merr.), and plots were left undisturbed after harvest. Spring tillage included one pass with a disk and one pass with a field cultivator. Plot size varied from 0.01 ha to 0.03 ha. Soil samples (0-15 cm) were collected with a hand probe from each plot, and analyzed for pH, organic matter content, extractable SO₄²⁻, available P, and exchangeable K, Ca, and Mg (Table 1), according to the methods outlined by Brown (1998). The experimental design was a randomized complete block with four treatments and four replications. Fertilizer treatments were: i) control; ii) 34 kg S/ha applied as 13-33-0-15S (SEF); iii) 34 kg S/ha applied as 21-0-0-24S (AMS); and iv) 34 kg S/ha applied as liquid 12-0-0-26S (ATS). The granular

materials (treatments ii and iii) were applied at planting as a subsurface band 5 cm to the side of the seed row and 7.5 cm below the soil surface, while the liquid was applied at planting as a surface dribble 5 cm to the side of the seed row. Six weeks after planting, urea ammonium nitrate (UAN) liquid fertilizer was applied to all plots with a spoke wheel applicator. Accounting for the N applied with the S fertilizer treatments, all plots received a total of 174 kg N/ha.

Maize was planted in early May each year in 76-cm rows at a seeding rate of 74,000 plants/ha. Each plot consisted of five rows. Stand counts were conducted approximately six weeks after planting. The effect of S fertilizer on early-season nutrient uptake was determined by analysis of whole-plant samples collected at the five-leaf (V5) growth stage. Ear-leaf samples were also collected at the mid-silk growth stage and analyzed for total nutrient content. The center three rows of each plot were harvested with a small plot combine equipped with a moisture meter and electronic scale to determine yield and grain moisture. To compare nutrient-use efficiency among the S sources, the agronomic efficiency (AE) of the S fertilizers was calculated with Eq. 1:

$$AE = (GW_F - GW_U)/SF \quad (1)$$

where GW_F is grain weight from a fertilized plot, GW_U is grain weight from the control plot, and SF is the amount of S fertilizer applied.

Table 1. Mean initial soil test levels for Clarion loam and silt loam.

Soil Test Parameter	Mean	Range [†]
Available (Bray-1) P, mg/kg	29 (VH)	13 (OPT) – 55 (VH) [‡]
Exchangeable K, mg/kg	140 (OPT)	98 (L) – 146 (H)
Exchangeable Ca, mg/kg	2423	2178 – 4052
Exchangeable Mg, mg/kg	291	322 – 540
Extractable S, mg/kg	5.9	1 – 13
pH	6.7	5.5 – 7.4
Organic Matter, g/kg	26	19 – 44

[†] Range documents variability encountered among individual plots.

[‡] Soil-test ratings, such as those for P and K, are not available for extractable S, although 10 mg/kg is generally considered sufficient.

Results and Discussion

With few exceptions, S availability and organic matter content at our sites were low, while other nutrient levels were adequate for maize production (Table 1). Subsoil levels of extractable S did not increase significantly with depth, as shown for the Clarion loam in 2006 (Figure 1). Applying S had no effect on seedling emergence, which averaged 88%, 87%, and 87% in 2006, 2007, and 2008, respectively. This was expected, since the materials were not placed in the seed furrow. Sulfur addition did affect early plant growth, as well as nitrogen (N) and S concentrations (Table 2). Applying 34 kg S/ha as SEF significantly increased mean V5 plant dry weight in all three years. Ammonium sulfate and ATS also tended to increase plant dry weight, but the response was not consistent. Whole-plant S concentrations at V5 were generally higher with all three materials than for the control (Table 2.). A tissue S concentration of 1.5 g/kg is considered adequate for maize at the V5 growth stage (Mills and Jones 1996). As predicted by the initial soil tests (Table 1), whole-plant P concentrations at V5 (Table 2) were within or above the sufficiency ranges. Nitrogen concentrations, however, were below the critical value 35 g/kg (Mills and Jones 1996). This suggests that the N applied with the S fertilizers plus residual soil N were not sufficient for maize growth before additional N was applied six weeks after planting. With respect to K, low tissue K concentrations (<25 g/kg) in 2007 presumably reflected low soil test K in four of the 16 plots.

At the mid-silk stage, ear leaf S concentrations (data not shown) were below the sufficiency range of 2.1 to 5.0 g/kg (Mills and Jones 1996), even when S was applied. The 3-year mean ear-leaf concentration for all treatments was 1.6 g/kg. During the 2006 and 2007 growing seasons, precipitation was below normal, and because soils supply S mainly via mass flow (Barber 1995), low concentrations of S in soil solution and low soil water content are suspected to have reduced the amount of S reaching the roots. In 2006 and 2007, maize yield and grain moisture content were not significantly affected by S fertilizer application (Table 3), even though 34 kg S/ha as SEF increased grain yield by 0.42 Mg/ha compared with the control. This difference was not significant ($p < 0.05$) because of the variability among the plots, but with a less conservative level

($p < 0.10$), the difference was significant. In 2007, 34 kg S/ha as either SEF or AMS increased grain yield by 0.63 Mg/ha compared with the control – a difference that was again significant at $p < 0.10$ (Table 3). Again, below-normal precipitation during part of the 2006 and 2007 growing seasons and inherent soil variability at these locations likely affected the measured yield response to S fertilizer. In 2008, maize grain yield was increased 0.76 Mg/ha ($p < 0.05$) with 34 kg S/ha as SEF (Table 3). Sulfur removal with harvested grain and plant residues (data not shown) was higher when S fertilizer was applied, suggesting that the maize took advantage of an increased S supply in 2008.

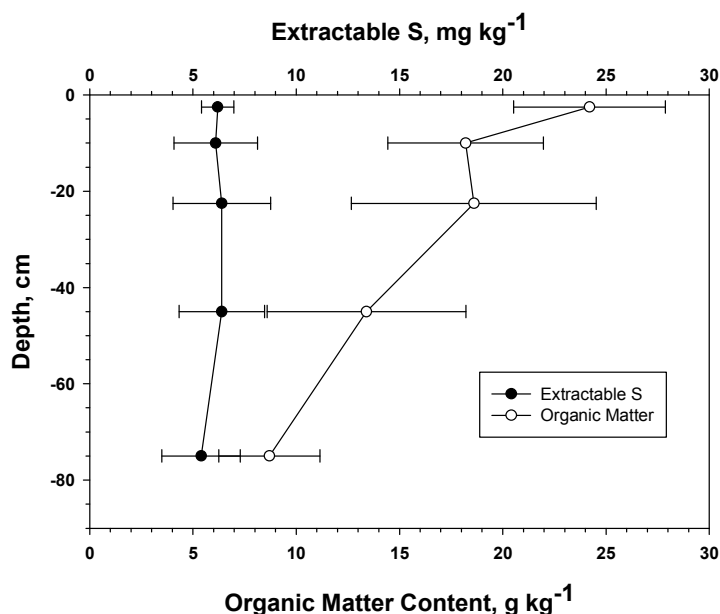


Figure 1. Extractable S and organic matter content in the soil profile of Clarion loam. Soil samples were collected to a depth of 1 m before planting in 2006. Bars indicate standard deviation of the mean of ten samples.

Agronomic efficiency of the three S sources was calculated to provide an index for grain produced per unit of applied S. In 2006 and 2008, SEF was clearly the most effective S source (Table 3). Although available P in the soils was sufficient for maize growth (Table 1), there may have been some beneficial effect of the additional P in the SEF material. In an experiment with ^{35}S -labelled fertilizer, Friesen (1996) found that P mixed with S increased maize growth and S recovery more than when P and S fertilizers were physically separated. The results were attributed to a P and N nutritional requirement of S-oxidizing microorganisms in the soil.

Table 2. Effect of 34 kg S/ha on whole-plant dry weight, and sulfur (S), nitrogen (N), phosphorus (P), and potassium (K) concentrations at the V5 growth stage of maize grown on three soils. Values are least square means of four replications. Values followed by the same letter are not significantly different at the 0.05 level.

Treatment	Dry Weight	Nutrient			
		S	N	P	K
	g/plant	----- g/kg -----			
2006 Field Trial					
Control	4.3b	1.7b	31.3b	4.7a	41.6a
13-33-0-15S (SEF)	7.4a	2.1a	34.3a	4.6a	35.1a
21-0-0-24S (AMS)	6.1ab	2.1a	34.9a	4.4a	38.1a
12-0-0-26S (ATS)	5.8ab	2.3a	31.8b	4.2b	39.2a
2007 Field Trial					
Control	6.0b	1.6b	28.9b	3.4a	20.1a
13-33-0-15S (SEF)	8.9a	2.0a	32.4ab	3.7a	17.1a
21-0-0-24S (AMS)	7.2ab	1.9a	32.7a	3.1a	18.5a
12-0-0-26S (ATS)	5.5b	1.8a	29.4ab	3.3a	18.1a
2008 Field Trial					
Control	5.4b	1.5b	24.0b	3.6a	37.3a
13-33-0-15S (SEF)	7.9a	1.7ab	26.4ab	3.9a	32.3a
21-0-0-24S (AMS)	6.6ab	1.9a	29.6a	3.3a	32.2a
12-0-0-26S (ATS)	7.0ab	1.8ab	25.0ab	3.2b	34.1a

Table 3. Effect of 34 kg S/ha on grain yields and grain moisture at harvest of maize grown on three soils. Values are least square means of four replications. Values followed by the same letter are not significantly different at the 0.05 level. Agronomic efficiency of S fertilizer sources is shown for comparative purposes.

Treatment	Grain Yield Mg/ha	Grain Moisture g/kg	Agronomic Efficiency kg grain (kg S) ⁻¹
2006 Field Trial			
Control	10.65a	145a	-
13-33-0-15S (SEF)	11.07a	146a	12.3
21-0-0-24S (AMS)	10.76a	145a	3.3
12-0-0-26S (ATS)	10.72a	144a	2.1
2007 Field Trial			
Control	11.04a	149a	-
13-33-0-15S (SEF)	11.67a	146a	19.3
21-0-0-24S (AMS)	11.67a	147a	19.1
12-0-0-26S (ATS)	11.47a	146a	12.1
2008 Field Trial			
Control	12.05b	172a	-
13-33-0-15S (SEF)	12.81a	166a	22.5
21-0-0-24S (AMS)	12.05b	170a	0.1
12-0-0-26S (ATS)	12.18b	167a	4.1

Summary

Field trials were conducted to evaluate S fertilizer responses on eroded hill slopes in central Iowa, USA. Application of 34 kg S/ha as SEF increased V5 mean plant dry weight each year. Whole-plant S levels at V5 were generally higher for all S sources. In 2006 and 2007, maize grain yield was not increased and moisture content was not reduced by S application. In 2008, yield was increased 0.76 Mg/ha with SEF. Agronomic efficiency showed SEF to be the most effective S source. Below-normal precipitation during 2006 and 2007 growing seasons and inherent soil variability likely affected our S yield responses. These results suggest that S may become a limiting nutrient for Midwestern USA maize production, because surface soil on hill slopes is often eroded, common fertilizer materials contain less S as an impurity, and atmospheric deposition of S has decreased.

References

- Barber SA (1995) Soil nutrient bioavailability: A mechanistic approach – 2nd Edition. (John Wiley & Sons: New York).
- Brown JR (1998) Recommended Chemical Soil Test Procedures for the North Central Region (Revised). *Missouri Agr. Exp. Sta. SB1001*. (Columbia, MO).
- Friesen DK (1996) Influence of co-granulated nutrients and granule size on plant responses to elemental sulfur in compound fertilizers. *Nutrient Cycling in Agroecosystems* **46**, 81-90.
- Hoeft RG, Sawyer JE, Vanden Heuvel RM, Schmitt MA, Brinkman GS (1985) Corn response to sulfur on Illinois soils *Journal of Fertilizer Issues* **2**, 95-104.
- Lang B, Sawyer J, Barnhart S (2006) Dealing with sulfur deficiency in northeast Iowa alfalfa production. In 'Proc. 18th Annual Integrated Crop Management Conference'. pp.225-235. (Iowa State University: Ames).
- Mills HA, Jones Jr JB (1996) Plant analysis handbook II. (MicroMacro Publishing: Athens, GA).
- Rehm GW (1984) Source and rate of sulfur for corn production. *Journal of Fertilizer Issues* **3**, 99-103.
- Rehm GW (2005) Sulfur management for corn growth with conservation tillage. *Soil Science Society of America Journal* **69**, 709-717.
- Stecker JA, Buchholz DD, Tracy PW (1995) Fertilizer sulfur effects on corn yield and plant sulfur concentration. *Journal of Production Agriculture* **8**, 61-65.
- Tabatabai MA, Bremner JM (1972) Distribution of total and available sulfur in selected soils and soil profiles. *Agronomy Journal* **64**, 40-45.

Isotopic determination of sulfur (S) availability from S coated mono-ammonium phosphate

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Abstract

An evaluation of three novel elemental sulfur (S⁰) coated mono-ammonium phosphate (MAP) products ((MAP with coarse (75-100µm) S⁰ coating (MAP75), MAP with fine (17-24µm) S⁰ coating (MAP17), and MAP with 1/3 coarse S⁰, 1/3 fine S⁰, and 1/3 sulfate coating (MAPM)) was undertaken in an intact core pot trial using red clover (*Trifolium pratense*) and compared with single superphosphate (SSP). Sulfur (S) uptake from coated S sources was not significantly different ($p < 0.05$) from SSP after 120 days of growth. Between 34% and 53% plant S was derived from the fertiliser sources. There was no significant difference in % fertiliser recovery between MAPM and SSP at either harvest and at both harvests fertiliser S recovery was in the order MAP < MAP75 < MAP17 < MAPM < SSP.

The key finding was that a MAP coated with 1/3 sulfate and 2/3 S⁰ was able to supply clover with the same amount of S, at the same rate, as SSP over 120 days. Under leaching conditions, this availability may result in slower, longer release of S as the coarser fraction slowly meets plant demands and protects added S from leaching.

Key Words

Elemental sulfur, oxidation, single superphosphate, New England, *Trifolium pratense*

Introduction

The shift from single superphosphate (SSP) to phosphorus (P) sources with less sulfur (S) such as triple superphosphate has increased the incidence of S deficiency in New England pastures (Blair 2008). Although SSP has historically been the main fertiliser used in the New England, S⁰ may be a cheaper more effective alternative S source (Blair 2008). Microbial oxidation is required to convert S⁰ to sulfate before plant uptake. The rate of release is largely determined by particle size and factors affecting microbial activity including temperature and moisture (Solberg *et al.* 2005). As climatic constraints reduce S⁰ oxidation in the New England, the reduction of S⁰ particle size to <150µm is required to provide sufficient sulfate for plant demand (Weir *et al.* 1963). In coarse textured soils, sulfate is susceptible to leaching and hence strategies that may slow the release of sulfate from S⁰ may increase the efficiency of applied S. Various models have been developed to calculate a given release of S from S⁰ based fertilisers at particular environmental parameters and particle sizes (McCaskill and Blair 1989). This experiment aimed to test the relative availability of S from different sulfate and S⁰ coatings on MAP to determine the fraction contributing to S fertiliser release from three novel S fertilisers.

Methods

Pot trial preparation and site background

A pot trial was conducted at the University of New England's (UNE) glasshouse facility, Armidale New South Wales (NSW). The coarse textured Grey Tenosol (Isbell 2002) (pH: 5.8) used in the trial was sourced from the UNE Newholme research property, approximately 15 km north of Armidale NSW. Twenty four 30 cm (ø) x 30 cm (h) steel, cylindrical undisturbed intact soil cores weighing approximately 40 kg were collected from a perennial, dormant, pasture, with no known fertiliser history. The native pasture composition included *Themeda australis*, *Austrodanthonia* spp., *Poa sieberana* and *Bothriochloa macra*.

Soil treatment and application

Pots were arranged in a randomised factorial design consisting of six treatments with four replicates. Treatments included a control, SSP (contains 12% S as sulfate), MAP (containing 1.6% S as sulfate), MAP75 with 75-100µm S⁰ coating (100% S), MAP17 with 17-24µm S⁰ coating (100% S) and MAPM consisting of 1/3 75-100µm, 1/3 17-24µm and 1/3 sulfate coating (containing 8.9% S). Reverse dilution methodology was used to label native S as radioactive commercial fertilisers are unavailable. When carrier

free $^{35}\text{SO}_4$ radioactive S isotope (^{35}S) is applied two assumptions are made. First, the radiotracer, when applied, is distributed throughout the native S pool, hence all native S from which the plant sources S, is uniformly labeled. Second, the application of unlabelled fertiliser S does not affect the movement of tracer S between S pool fractions. 250 mL of ^{35}S with a half life of 87 days was added to each pot at 596 mCi/mL. Intact cores were allowed to equilibrate for 50 days prior to S fertiliser application. An application rate of 20 kg S/ha was used to adequately provide S to ensure prolonged, non S deficient conditions to evaluate relative S release. Phosphorus (P) and nitrogen (N) application was balanced using AeroPhos (26% P) and urea (46% N) respectively. Potassium (K) was added to each pot at 50 kg K/ha as a KCl solution, molybdenum was added as ammonium molybdate and boron (B) as boric acid at < 1 kg nutrient/ha with the K solution. Red clover (*Trifolium pratense*) seed was broadcasted over each pot at > 20 kg/ha following surface nutrient application. After broadcasting, seed and fertiliser were incorporated into the first 2 cm of soil. Based on pot weight each pot was watered to no more than 90% of maximum field capacity each week.

Harvest and analysis

Clover tops were removed at 2cm above the soil surface after 60 and 120 days of growth, placed in paper bags and oven dried at 105°C for 7 days. Samples were digested using the sealed chamber digestion method and nutrient content was determined using inductively coupled plasma-atomic emission spectrometry (ICP-AES), with plant ^{35}S content determined by liquid scintillation counting following scintillant addition (Anderson and Henderson 1986; Till *et al.* 1984).

Results

The soil used was responsive to S with significant growth increases to all S additions (Figure 1). All S sources took up more S than the control and MAP treatments at both harvests and there were no differences between MAP17, MAPM and SSP at either harvest.

Less than 40% of the S in the clover in the MAP S treatments was derived from the fertiliser at the first harvest (data not shown) which compares with 50% from SSP. There were no significant differences in the % of S in the plant derived from the fertilisers between the MAP S treatments and SSP at the second harvest.

There was no significant difference in % fertiliser recovery between MAPM and SSP at either harvest (Figure 1) and at both harvests fertiliser S recovery was in the order MAP < MAP75 < MAP17 < MAPM < SSP.

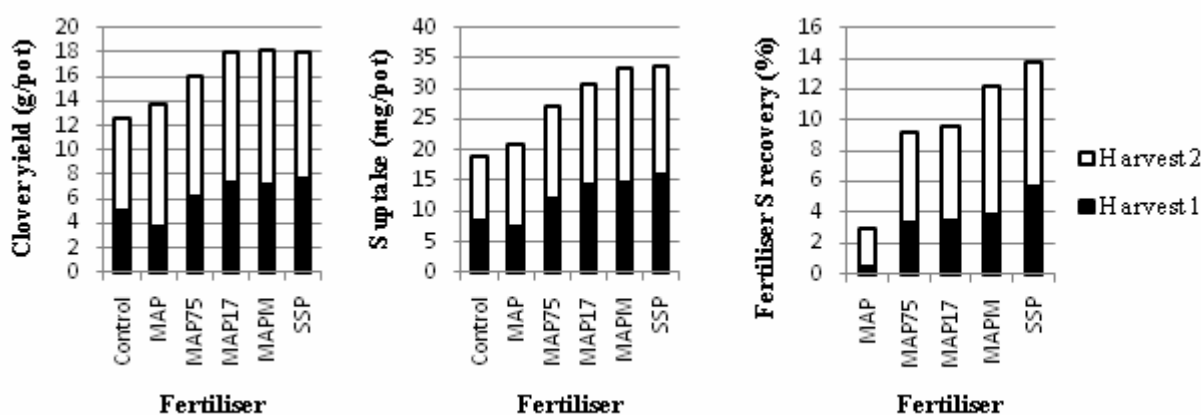


Figure 2. Dry matter, S uptake and the % of recovered fertiliser S of plant tops in *Trifolium pratense* at 60 days (harvest 1) and 120 days (harvest 2) of growth.

Discussion

Tissue S concentrations indicated that 20 kg S/ha met plant requirements for sulfate as either sulfate or fine S^0 oxidation. Increasing temperatures over the growing period also provided favourable conditions for microbial oxidation of S^0 , increased mineralisation and deeper root growth for S absorption (Solberg *et al.* 2005). Applications of any S fertiliser containing at least 1.6% sulfate and S^0 of less than 150µm particle size at 20 kg S/ha will provide adequate S to meet plant S demand over 120 days. However, the key finding was that MAPM was as available in all facets as the SSP source, despite a 2/3 S^0 component and less than ideal initial oxidation conditions.

Sulfur recovery values were reduced by 10% in coarse and fine S⁰ sources compared with SSP (Figure 1). Coarse S⁰ persists longer in soils due to a lower surface area to volume ratio and consequent decrease in oxidation rate (Jones and Ruckman 1966). Sulfur oxidation in the first 60 days of plant growth was also reduced due to lower temperatures and lag times in microbial population growth (Solberg *et al.* 2005).

Conclusion

There was no difference between a S source consisting of 2/3 S⁰ and 1/3 sulfate and a 100% sulfate SSP source with respect to clover growth and S uptake over 120 days. The high (20 kg S/ha) rate of S applied and the closed nature of the trial minimised the opportunity to examine longer term release rates, however there was evidence in this trial that a combination of sulfate and S⁰ sources is able to supply equivalent and sufficient S for plant growth under New England conditions.

References

- Anderson DL, Henderson LJ (1986) Sealed chamber digestion for plant nutrient analyses. *Agronomy Journal* **78**, 937-939.
- Blair GJ (2008) SSP: Single superphosphate, a scenario slowly passing. *14th Australian Society of Agronomy Conference* Adelaide, South Australia.
- Isbell R (2002) The Australian soil classification revised edition. *CSIRO Publishing*.
- Jones MB, Ruckman JE (1966) Gypsum and elemental sulfur as fertilizers on annual grassland. *Agronomy Journal* **58**, 409-412.
- McCaskill MR, Blair GJ (1989) A model for the release of sulfur from elemental S and superphosphate. *Fertilizer Research* **19**, 77-84.
- Solberg ED, Malhi SS, Nyborg M, Gill KS (2005) Temperature, soil moisture, and antecedent sulfur application effects on recovery of elemental sulfur as SO₄-S in incubated soils. *Communications in Soil Science and Plant Analysis* **36**, 863-874.
- Till AR, McArthur GS, Rocks RL (1984) An automated procedure for the simultaneous determination of sulphur and phosphorus and of radioactivity in biological samples. *Proceedings of Sulfur 84, Alberta, Canada* Sulfur Development Institute Canada (SDIC), Calgary, Canada, 649-660.
- Weir RG, Barkus B, Atkinson WT (1963) The effect of particle size on the availability of brimstone sulphur to white clover. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 314-318.

Management of Multimicronutrients Deficiencies for Enhancing Yield of Crops

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Abstract

The multi-micronutrient mixture grades for Zn-deficiency (grade-II : Fe-2.0%, Mn-0.5%, Zn-8.0%, Cu-0.5%, B-0.5%), Fe-deficiency (grade-III: Fe-6.0%, Mn-1.0%, Zn-4.0%, Cu-0.3%, B-0.5%) and Zn+Fe-deficiency (grade-IV : Fe-4.0%, Mn-1.0%, Zn-6.0%, Cu-0.5%, B-0.5%) besides normal grade for foliar application (grade-I : Fe-2.0%, Mn-0.5%, Zn-4.0%, Cu-0.3%, B-0.5%) at 1% and soil application grade –V (Fe-2.0%, Mn-0.5%, Zn-5.0%, Cu-0.2%, B-0.5%) at 20 kg/ha were prepared. Efficacy of these mixtures was tested in important food crops by conducting field experiments on different soil type having marginal to deficient Fe and Zn status at various locations in Gujarat state of India. Amongst the foliar grades, Grade-III (for Fe deficient soil) and Grades-IV (For Zn and Fe deficient soils) were found more effective in most of the crops of various groups viz., cereals (maize, sorghum, Pearl millet and wheat), vegetables (potato, cabbage, okra) and pulse like pigeon pea. The soil application Grade-V was found more beneficial in mustard while general foliar grade (Grade- I) was found effective in paddy. Depending upon the soil status for Zn, Fe or Zn+Fe deficiencies, foliar application of corresponding grades @ 1% or soil application @ 20 kg/ha were found effective in increasing yield of different crops and soil types of Gujarat, India.

Key Words

Multimicronutrients mixtures, balanced nutrition, micronutrients efficacy

Introduction

Continuous use of high analysis fertilizers under intensified cropping and neglect of organic manures manifested the occurrence of wide spread micronutrients deficiencies; especially of Zn and Fe in light textured soils of India after 1960. But, later multiple nutrient deficiencies were reported in crops for N, NP, NPFe, NPFeZn, NPFeZnK, NPZnKS, NPZnKSB and NPZnKSMnMo within a time frame of 1960 to 2005. Multinutrient deficiencies are emerging for Zn + Fe in swell- shrink soils, Zn + Mn or Zn + Fe + Mn in alluvial soils of Indo-Gangatic plains, Zn + Fe, Zn + B, Zn + Fe + B in highly calcareous soils of Bihar, Gujarat, Zn + B in acid leached Alfisols, red and Lateritic soils of India (Singh 2006; Singh and Bahera 2007). Despite application of adequate quantity of NPK, the yield remains low due to hidden hunger of micronutrients like Fe, Cu, Mn and B.

The multi-micronutrients mixture facilitate the application of the wide range of plant nutrients in the proportion and to suit the specific requirements of a crop in different stages of growth, and are more relevant under site specific nutrient management practices (Hegde 2007). The low use efficiency of major fertilizers, supplying major nutrient, in large proportion can be improved by their modifications to lessen the negative aspects as well as trying to combine one or two more nutrients so that with the same application effort, crop benefits with multi-nutrient needs. Therefore, there is a need to promote balanced fertilization for which use of appropriate multi-micronutrient mixture grades would play a big role to improve nutrients use efficiency and enhance crops productivity for food and nutritional security.

Methods

Most of the soils of Gujarat have been reported to be deficient in Zn and Fe (Patel 1998). Therefore, the Zn and Fe deficiency is one of the most frequently encountered micronutrient deficiencies besides hidden hungers of other micronutrients in different crops grown in the state. The supplementation of micronutrients through multi-micronutrients mixture under such situations becomes more important to provide balanced nutrition to the crops. Keeping this in view, the multi-micronutrients mixtures were prepared based on prevailing deficiencies of Zn and Fe in soils of Gujarat to provide balanced nutrition of micronutrients in different crops (Table 1); and their efficacy was tested on soils having marginal to deficient status in available (DTPA-extractable) Zn / Fe or Zn+Fe.

Table 1. Composition of multimicronutrients mixture grades

Sr. No.	Grade	Content (%)				
		Fe	Mn	Zn	Cu	B
	<u>For foliar spray</u>					
1.	Grade-I (General)	2.0	0.5	4.0	0.3	0.5
2.	Grade-II (for Zn deficiency)	2.0	0.5	8.0	0.5	0.5
3.	Grade-III (for Fe deficiency)	6.0	1.0	4.0	0.3	0.5
4.	Grade-IV (for Zn & Fe deficiency)	4.0	1.0	6.0	0.5	0.5
	<u>For soil application</u>					
5.	Grade-V (Soil application)	2.0	0.5	5.0	0.2	0.5

The rate of application of the Grades (Sr. No. 1 to Sr. No.4) for foliar spray was kept at 1 % during crop growth period with two to three sprays depending upon the duration of the crop; and the soil application (Sr. No. 5) was @ 20 kg/ha as basal.

The treatments were: T₁ Control (NPK+ water spray), T₂ Grade-I (General Grade for foliar spray), T₃ Grade-II (for Zn deficiency), T₄ Grade-III (for Fe Deficiency), T₅ Grade-IV (for Zn and Fe Deficiency), Grade-V (General Grade for soil application) and T₇ Soil application as per soil test value (STV).

Experiments were continued for three to five years in different crops with four replications in randomized block design and the data were satisfactory analyzed on pooled basis.

The plant samples (grain / edible parts and straw / leaves) were taken at the harvest of different crops for determination of total contents of micronutrients for computation of micronutrient uptake. The samples were oven dried and finely ground in a S. S. Wiley mill; and digested with di-acid mixture of HNO₃: HClO₄ (3:1) as per the standard procedure and the micronutrient contents were determined by atomic absorption spectrophotometer (PE 3110). The soil samples drawn from the experimental field at harvest were analyzed for available micronutrients using 0.005 M DTPA extractant (Lindsay and Norvell 1978).

Results

Effect on crops yield

Amongst the cereals, the maximum improvement in *kharif* paddy grain was up to 766 kg/ha over control due to general foliar grade-I (Table 2). In case of vegetables, potato tuber yield was increased by 8190 kg/ha equivalent to 22.6 % increase over control (362.5 q/ha) due to foliar grade-III. The maximum net realization (Rs. 16129/ha) with CBR (1:2.02) was obtained due to soil application of grade-V (General grade) in okra. The maximum net realization (Rs. 34,439=00/ha) in cabbage was obtained due to the spray treatment of grade-IV (Fe & Zn deficiency) followed by soil application of micronutrients fertilizer as per STV (Rs. 33,425/ha). The CBR value for grade-IV and STV treatments were worked out as 1: 3.19 and 1: 3.17, respectively. The foliar application of grade-III produced the highest tuber yield of potato and recorded maximum net realization (Rs.73,220/ha) and net cost benefit ratio (CBR-1:2.20) among all the treatments. Soil application grade-V also gave comparable net realization (Rs. 63,519/ha) and economic return (CBR Rs.1:2.05). Therefore, use of foliar spray of grade-III and soil application grade-V of micronutrients were found almost equally beneficial in obtaining higher tuber yield and net realization the increase in pigeon pea grain yield was by 436 kg/ha due to grade – IV over control (1250 kg/ha).

The beneficial effects of the multi-micronutrients could be ascribed to the balanced nutrition of the crops and thereby improved crop growth as well as yield. The supplementation of multimicronutrients through foliar feeding during the crops growth period provided balanced nutrition to the crops for improvement in crops yields. Also, the addition of the micronutrients helps in better utilization of the major nutrients to produce higher yield of the crops. The hidden deficiencies of micronutrients are overcome due to their supplementation during the growth period, which results in better crop growth and thereby yield. The beneficial effect on use of multimicronutrients mixture have been reported in different crops for growth and yield of okra (Medhi and Kakati 1994), tomato (Bose and Tripathi 1996), wheat (Nazim 2005; El-Magid 2000), maize (El-nagar 2002) and soybean (Thiyageshwari and Ramanathan 2001).

Table 2. Effect of multi-micronutrients mixture application on yield of different crops (q/ha)

Treatments	Maize Grain (3)	Wheat Grain (3)	Kharif Paddy Grain (3)	Bajri Grain (5)	Okra Fruit (3)	Potato Tuber (3)	Cabbage Head (5)	Mustard Seed (3)	Pigeon pea Grain (3)
Location	Godhra	Vijapur	Navsari	Jamnagar	Anand	Deesa	Anand	S. K. Nagar	Khandha
Soil Type	Medium black	Sandy loam	Clayey	Medium black calcareous	Loamy sand	Sandy	Loamy sand	Sandy	Medium black
T ₁ control	16.9	35.9	56.8	21.4	56.3	362.5	228.4	18.1	12.5
T ₂ Grade-I	18.8	37.9	54.4	23.4	59.2	366.7	235.7	18.2	15.2
T ₃ Grade-II	20.6	38.2	50.2	24.2	59.9	378.2	241.0	18.2	15.4
T ₄ Grade-III	23.2	37.4	50.9	25.4	60.6	444.4	240.0	18.8	13.6
T ₅ Grade-IV	21.1	40.1	52.9	27.0	63.6	389.2	250.7	17.8	16.8
T ₆ Grade-V	21.9	35.2	53.6	28.6	63.8	411.7	239.8	18.9	14.6
T ₇ STV	21.0	41.4	52.5	28.8	62.7	376.4	244.1	19.8	13.8
LSD(P=0.05)	1.87	2.88	3.5	2.0	2.7	29.5	12.1	0.9	2.1
Y x T	NS	NS	NS	NS	-	NS	NS	-	NS

() Figure in parenthesis indicates experimental duration (years)

Table 3. Effect of multimicronutrients mixture application on micronutrients uptake (g/ha) by different cereals

Treatments	Wheat Grain (3)	Maize Grain (3)	Okra Fruit (3)	Cabbage Head (5)	Mustard Seed (3)	Wheat Grain (3)	Maize Grain (3)	Okra Fruit (3)	Cabbage Head (5)	Mustard Seed (3)
Location	Vijapur	Godhra	Anand	Anand	S. K. Nagar	Vijapur	Godhra	Anand	Anand	S. K. Nagar
Soil Type	Sandy loam	Medium black	Loamy sand	Loamy sand	Sandy	Sandy loam	Medium Black	Loamy sand	Loamy Sand	Sandy
	Fe Uptake					Zn Uptake				
T ₁ control	216	36.9	30.0	260.9	89	56.9	35.2	12.5	32.2	38.2
T ₂ Grade-I	192	39.9	34.7	296.6	30	64.4	38.4	13.4	35.2	46.6
T ₃ Grade-II	233	44.0	32.8	338.7	36	71.3	46.9	13.7	40.2	54.1
T ₄ Grade-III	177	52.8	34.8	312.8	39	65.0	51.4	16.0	40.1	53.1
T ₅ Grade-IV	233	46.2	35.9	319.9	47	70.3	45.0	16.5	39.7	50.5
T ₆ Grade-V	212	49.4	37.3	318.2	110	64.3	43.9	15.6	41.8	60.0
T ₇ STV	228	51.6	37.5	270.9	35	74.4	45.9	13.5	43.3	66.0
LSD(P=0.05)	33	6.6	NS	29.0	2	9.9	5.1	NS	5.9	3.6

() Figure in parenthesis indicates experimental duration (years)

Uptake of Micronutrients

The data on total uptake of micronutrients for some of the important crops (Table 3) revealed that the treatments of foliar as well as soil application of multi-micronutrients mixture enhanced the uptake of micronutrients in edible portion of the different crops over control. It has therefore, indicated an increase in the micronutrients use efficiency by different crops due to use of multi-micronutrients mixture application over control. The improvement in the nutrients use efficiency could be attributed to an enhancement in absorption and assimilation of the micronutrients which provided balanced nutrition to the crops for higher growth; and thereby nutrients uptake which ultimately resulted into higher yield of the crops. The increase in content of micronutrients and their uptake by different crops due to use of multi-micronutrients fertilizers have also been reported by several workers as mentioned earlier.

The overall results indicated superiority of different grades in increasing crop yields. Amongst the foliar grades, Grade-III (for Fe deficient soil) and Grades-IV (For Zn and Fe deficient soils) were found more effective in most of the crops of various groups viz., cereals (maize, sorghum, pearl millet and wheat), vegetables (potato, cabbage, okra) and pulse like pigeon pea. The soil application Grade-V was found more beneficial in oilseed like mustard; while the general foliar grade (Grade- I) was found effective in paddy. Thus, in general, the use of multimicronutrients mixture foliar grades depending upon the soil deficient condition for either of Fe, Zn or Fe and Zn, the foliar application of corresponding grades @ 1% and soil application @ 20 kg/ha have shown their better effectiveness in increasing yield of different crops and various soils types of Gujarat.

In general, the average contents of DTPA-extractable Fe and Zn of the soil improved due to application of multimicronutrients through soil application at the end of the experiment. However, the improvement in DTPA- micronutrients was not that alarming to adversely affect the soil health.

Conclusion

Field crops are generally sensitive to micronutrients stress and suffer due to hidden hunger of multi-micronutrient deficiencies. Therefore, correction of hidden hungers or deficiencies of micronutrients are necessary for balanced nutrition to get higher yield of crops on sustainable basis. The multi micronutrients fertilizers mixture grades prepared on the basis of micronutrients deficiency status of Gujarat soils proved beneficial in increasing yield of different crops under varied agro-climatic conditions and different types of soils. In general, the multi micronutrients mixture (grade-V) having Fe 0.2%, Mn 0.5%, Zn 5%, Cu 0.2% and B 0.5% for soil application at 20 kg/ha and foliar application grade-III (for Fe deficiency) having Fe 6%, Mn 1%, Zn 4%, Cu 0.3% and B 0.5% as well as grade-IV (for Fe and Zn deficiency) at 1% having Fe 4%, Mn 1%, Zn 6%, Cu 0.5% and B 0.5% for spraying at 15, 30, 45 / 60 days after sowing were found beneficial to get higher yield of different crops and net realization. The improved content of micronutrients in food parts help correcting malnutrition problems of Fe and Zn in human.

References

- Bose US, Tripathi SK (1996) Effect of micronutrients on growth, yield and quality of tomato cv. Pusa Ruby in M. P. *Crop Research* **12**, 61 –64.
- El-Magid AAA, Knany RE, El-Fotoh HGA (2000) Effect of foliar application of some micronutrients on wheat yield and quality. *Annals Agricultural Science Cairo* 1(special), 301-313.
- El-Nagar GR (2002). Effect of nitrogen fertilizer and foliar application with micronutrients on white and yellow maize. *Australian Journal of Agricultural Science* **33(3)**, 85–102.
- Hegde DM, Sudhakara Babu SN, Murthy IYLN (2007) Role of Customized Fertilizers in the Improvement of Productivity of Different Crops and Cropping Systems. In Proceedings of national seminar on “Standards and Technology of Value Added / Fortified / Customized Fertilizers as a Source of Plant Nutrients”. (ICAR- IISS, Bhopal, India).
- Lindsay WL, Norvell WA (1978) Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of American Journal* **42**, 421-428.
- Medhi G, Kakati RN (1994) Effect of micronutrients in increasing the growth and yield of *bhendi* (*Abelmoschus esculentus* L.). *Horticulture Journal* **7(2)**, 155-158.
- Nazim H, Khan MA, Javed MA (2005) Effect of foliar application of of plant micronutrient mixture on growth and yield of wheat (*Triticum aestivum* L.), *Pakistan Journal of Biological Science* **8(8)**, 1096-1099.
- Patel KP, George V, Patel KC (1998) Micronutrient Research in Gujarat. *Journal of Gujarat Society of Agronomy and Soil Science* **1 (1)**, 27-32.
- Singh MV (2006) Micro- and Secondary- Nutrients and Pollutant Elements Research in India. In "Coordinator Report – AICRP Micro- and Secondary- Nutrients and Pollutant Elements in Soils and Plants" (ICAR- IISS, Bhopal, India) **30**, 1-110.
- Singh MV, Bahera SK (2007) Emerging Multiple Nutrient Deficiencies and Need for Developing Customized Fertilizers for Enhancing Crop Production in India. In Proceedings of national seminar on “Standards and Technology of Value Added / Fortified / Customized Fertilizers as a Source of Plant Nutrients”. (ICAR- IISS, Bhopal, India).
- Thiyageshwari S, Ramanathan G (2001) Uptake of nutrients as influenced by application of micronutrients and cytozyme to soybean in Inceptisol. *Journal of Soils and Crops* **11(1)**, 1- 6.

Management Strategies to Improve Yield and Nitrogen Use of Spring Wheat and Field Pea in the Semi-Arid Northern Great Plains USA.

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Abstract

Available water and N fertility are primary constraints to crop production in the northern Great Plains of the USA. A field trial was initiated in 2004 to compare four crop rotations in a complete factorial of two tillage and two management systems. Rotations were continuous spring wheat (SW), pea-SW, barley hay-pea-SW, and barley hay-corn-pea-SW. Tillage systems were no till and field cultivator tillage, while management systems were conventional and ecological. Conventional management included broadcast nitrogen fertilizer, standard seeding rates, and short stubble height. Ecological management practices varied by crop, and included banded nitrogen fertilizer for cereals, increased seeding rate, delayed planting date for SW, and taller stubble height. Continuous SW grain yield was 26% lower than SW in more diverse rotations. Pea grain yield was 18% lower in 2-yr rotations than in more diverse rotations. Ecologically managed SW yielded 29% less than conventionally managed SW, presumably due to the delayed planting date. Ecological management of pea resulted in 12% greater yield compared to conventional management. Tillage system rarely impacted crop yield. Yield increases in SW were related to increased N use efficiency.

Key Words

Crop rotation; Zero tillage; Nutrient management; Long term experiment; Wheat production, Pea production.

Introduction

Crop productivity in the semi-arid northern Great Plains (NGP) of the USA and Canada typically is limited by available soil water and plant available N. A SW-fallow rotation is most common to increase storage of soil water for the subsequent crop, but this practice increases the risk of soil erosion from wind and water and typically reduces soil C and other measures of soil quality. Another challenge facing producers is the reliance on expensive N fertilizer. Diversified crop rotations and inclusion of legumes could improve rotational productivity and nutrient cycling, lower rotational N requirements, and reduce input costs. Further research is warranted to identify farming systems that lower production risk, improve productivity, and provide sustainable environmental benefits. Management practices that alter planting date, fertilizer placement, and seeding rate could contribute to more sustainable and competitive cropping systems. This report addresses N use and crop yield results for different crop rotations and tillage and management systems for the first four years of a long-term, multidisciplinary project. Other components under consideration, but not reported here, are influences of crop diversification, tillage, and management system on crop yield and quality, water and nitrogen use, soil quality, microbial diversity, carbon sequestration, and pest dynamics.

Methods

Site and soil description

The field site location was approximately 8 km northwest of Sidney, Montana, USA (latitude 47°46'N; longitude 104°15'W; altitude 690 m) with a slope of 0.5%. Soil was a Williams loam (fine-loamy, mixed, superactive, frigid Typic Argiustolls) formed in glacial till with a pH of 6.9, organic matter of 1.8%, and soil-test P (Olsen) of 12 mg/kg for the 0-15 cm depth.

Experimental design, statistics, and treatments

The long-term dryland field trial initiated in 2004 compared four crop rotations with two tillage and two management systems. The experimental design was a randomized complete block in a split-plot arrangement with tillage system (no-tillage versus single-pass preplant tillage using a field cultivator) as the whole-plot factor. Subplots were a complete factorial of management system (conventional versus ecological) and rotation components (1, 2, 3, or 4 yr crop rotation). Rotations were continuous SW, SW-pea, SW-barley hay-

pea, and SW-barley hay-corn-pea, with all phases present each year. Conventional and ecological management practices varied by crop. Conventional management included standard seeding rates and broadcast nitrogen fertilizer for cereals and corn, and short stubble height at SW harvest. Ecological management included seeding rates 33% above conventional levels, banded nitrogen fertilizer for cereals, delayed planting date for SW, and taller stubble height at SW harvest. Plot size was 12.2 m by 12.2 m, with three replicates of each treatment combination for a total of 120 plots. Data were analysed with SAS using Proc Mixed with year and rep as random effects (SAS Institute, Cary, NC). Regression analysis using individual plot values was used to describe relationships between wheat yield and nitrogen use. Significant differences among treatments are reported at $P < 0.05$.

Urea was broadcast at 67 and 101 kg N/ha for barley and SW, respectively, in April prior to preplant tillage or no till planting. Corn plots received 78 kg N/ha as urea in May. Preplant conventional tillage to a 7-8 cm depth was with C-shank sweeps spaced 45-cm apart and 60 cm length coil-tooth spring harrows. Conventional- and ecological management barley 'Haybet', green field pea 'Majoret', and conventional management SW 'Reeder' were planted in early-mid April on 20-cm row spacing with double-shoot Barton disk openers for low disturbance planting and single-pass seeding and fertilization. Ecologically managed barley received 67 kg N/ha as urea banded at planting. Phosphorus (N-P₂O₅-K₂O: 11-52-0) and potash (0-0-60) were banded 5 cm below and to the side of seed at 56 and 48 kg/ha, respectively, when planting all wheat, barley, and pea plots. Barley and pea plots were rolled just after planting to push rocks back into soil after seeding to protect grain and forage harvest equipment. Ecologically managed SW was planted about three weeks after conventionally managed SW to allow the first emergence flush of wild oat (*Avena fatua*). Urea was banded at planting for ecologically managed SW at the same rate as conventionally managed SW. Pioneer '39T67-RR' hybrid corn was planted in mid-May. Barley, SW and corn were treated with labelled fungicide seed treatments.

Soil samples (5-cm diameter) were taken each spring and fall (except Fall 2006) to depth of 120 cm in 15 cm increments for the surface 30 cm and in 30 cm increments thereafter. Soil was dried at 25° C and analysed for nitrate and ammonium by flow injection. Nitrogen use was evaluated using data from 2006 and 2008 for a nitrogen harvest index (NHI) and for all years for a nitrogen removal index (NRI) and a nitrogen mass balance approach. The NHI represents the proportion of grain N in total biomass N, and the NRI represents the proportion of grain N relative to total N inputs (fertilizer N and preplant nitrate to 60 cm depth). The nitrogen mass balance was calculated by subtracting inputs (fertilizer and spring soil nitrate) from outputs (crop N uptake and residual fall soil nitrate), such that a negative value signifies N evolution while a positive value signifies N consumption by soil.

Yield

Biomass samples for pea, SW, and barley hay were harvested by hand clipping two 0.5 m² quadrats per plot. Yield samples for pea and SW were taken with a self-propelled combine equipped with a 1.5-m header harvesting a 10-m length. Crop biomass and grain samples were dried at 55° C and weighed. Yield and biomass data are presented on a 100% dry matter basis. Plot clean-off was done with a self-propelled combine equipped with a 4-m wide header and a straw chopper to evenly distribute residue. Stubble height was about 15-20 cm and 25-30 cm for conventionally- and ecologically managed SW, respectively.

Results

Weather

Growing season (April through September) precipitation and air temperature varied by year. The 2005, 2007, and 2008 growing seasons were characterized by average precipitation levels 8%, 6%, and 46% below the long term (48 yr) average of 272 mm rainfall, respectively, while 2006 was 14% above normal. The average air temperature during the growing season was 3%, 9%, and 4% warmer than the long term average for 2005, 2006, and 2007, respectively, while 2008 was 3% cooler than normal.

Spring wheat yield

Grain yield of continuous spring wheat was 26% lower than that of wheat grown in two, three, and four-year rotations (Figure 1). Additional increased rotational diversity did not impact grain yield, as wheat yields were similar in the two, three, or four year rotations and averaged 2.4 Mg/ha. Tillage treatment had little effect on wheat grain yield, as tilled and no till plot yields were similar and averaged 2.2 Mg/ha (Figure 1). However, grain yield was different between management systems where ecological management was 29% lower than

conventional management. The yield reduction in ecological managed wheat was most likely due to the delayed planting date. The interactions for wheat and pea yield were not significant at the 0.05 level for tillage×management, tillage×rotation, rotation×management, or tillage×management×rotation.

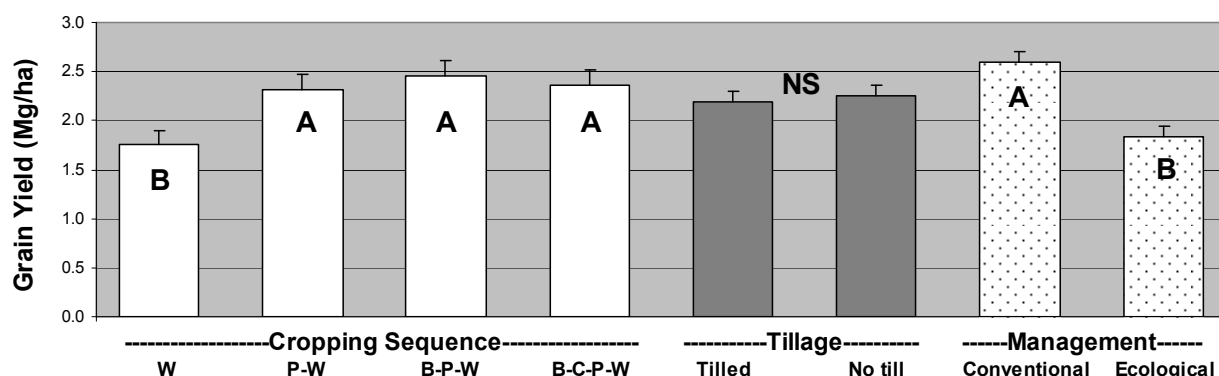


Figure 1. Mean spring wheat yield (SE) from four cropping sequences, two tillage systems, and two management systems. Different letters indicate a significant difference ($P < 0.05$) between treatments. NS is not significant. Note crop sequences are continuous wheat, pea-wheat, barley hay-pea-wheat, and barley hay-corn-pea-wheat.

Pea yield

Pea yield averaged 2.2, 2.0, 2.5, and 0.5 Mg/ha for 2005, 2006, 2007, and 2008 respectively. Greater yield in 2007 than other years was most likely related to the 79 mm above normal precipitation during May. Reduced pea yield in 2008 was reflective of the drought conditions, and grain yield was 77% lower than the 2005-2007 average. Grain yield of pea in the two-year rotation was 18% lower than that of pea grown in three and four-year rotations (Figure 2). Increasing the level of rotational diversity beyond the three yr did not impact grain yield, as pea yields were similar in the three and four year rotations and averaged 1.9 Mg/ha. Tillage treatment had little effect on pea grain yield, as tilled and no till plot yields were similar and averaged 1.8 Mg/ha (Figure 2). However, grain yield was different between management systems where ecological management was 12% greater than conventional management. The yield increase in ecological managed pea was most likely due in part to the greater seeding rate and to the increased stubble height of previous crops.

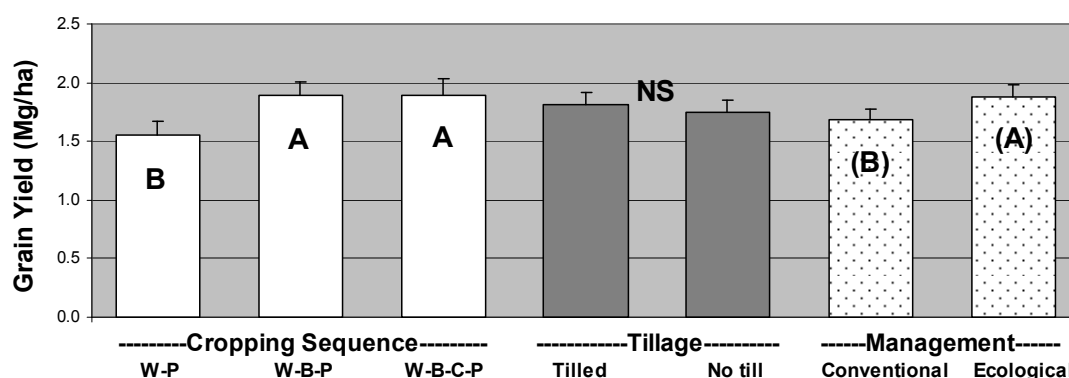


Figure 2. Mean pea yield (SE) from three cropping sequences, two tillage systems, and two management systems. Different letters indicate a significant difference ($P < 0.05$) between treatments. Letters in parenthesis indicate a significant difference at $P < 0.10$. NS is not significant, Note crop sequences are wheat-pea, wheat-barley hay-pea, and wheat-barley hay-corn-pea.

Wheat N use

Wheat yield was highly related ($P < 0.001$; $r^2 = 0.89$) to NRI, indicating the importance of N use efficiency in dryland wheat production. Indicators of N use efficiency were less favorable for continuous spring wheat than for wheat grown in two, three, and four-year rotations (Table 1). Increasing levels of rotational diversity did not impact nitrogen use efficiency as grain N, biomass N, residual soil nitrate, N balance, NHI, and NRI were similar in the two, three, or four year rotations. Tillage treatment generally had little effect on indicators of N use efficiency (Table 1). However, differences were apparent between management systems where ecological management typically used N less efficiently than conventional management (Table 1). A rotation×management interaction ($P < 0.05$) for grain N removal indicated conventional continuous wheat was similar to that of ecological wheat in two, three, and four-year rotations.

Table 1. Spring wheat grain N, biomass N, residual Fall soil nitrate (0-60 cm), N balance, nitrogen harvest index (NHI), and nitrogen removal index (NRI) means for 2005-2008.

Treatment	Grain N	Biomass N	Residual NO ₃ ⁻	N balance	NHI	NRI
	-----kg/ha-----					
Crop Sequence						
W	50.2 b	64.0 b	54.1	48.7 a	0.50 b	0.35 b
P-W	64.6 a	68.0 a	47.7	27.9 b	0.78 a	0.49 a
B-P-W	66.9 a	76.9 a	44.3	28.7 b	0.74 a	0.49 a
B-C-P-W	65.8 a	72.3 a	47.9	30.9 b	0.70 a	0.47 a
Tillage						
Tilled	60.8	70.7	55.3	27.0	0.65	0.45
No till	63.0	70.0	41.7	41.1	0.71	0.45
Management						
Conventional	71.2 a	69.9 b	54.4 a	19.2 b	0.82 a	0.52 a
Ecological	52.5 b	70.8 a	42.6 b	48.9 a	0.54 b	0.38 b

Pea N use

Increased levels of rotational diversity had variable effects on indicators of nitrogen use efficiency in pea (Table 2). Grain N was greater in three and four-year than two-year rotations. Biomass N was greater in four-year than either of the less diverse rotations. The NHI was greater in three-year than two and four-year rotations, though this difference could be attributed in part to a different crop preceding pea in each rotation. Residual soil nitrate, N balance, and NRI were similar among the three rotations. Tillage treatment and management system generally had little effect on indicators of N use efficiency, though grain N in pea was greater ($P<0.10$) in ecological than conventional management (Table 2).

Table 2. Pea grain N, biomass N, residual Fall soil nitrate (0-60 cm), N balance, nitrogen harvest index (NHI), and nitrogen removal index (NRI) means for 2005-2008.

Treatment	Grain N	Biomass N	Residual NO ₃ ⁻	N balance	NHI	NRI
	-----kg/ha-----					
Crop Sequence						
W-P	60.1 b	76.9 b	31.8	-58.1	0.64 b	2.5
W-B-P	72.0 a	83.2 b	28.8	-65.4	0.80 a	2.2
W-B-C-P	73.3 a	91.2 a	31.6	-59.6	0.68 b	2.1
Tillage						
Tilled	69.3	82.0	33.8	-62.9	0.70	2.3
No till	67.6	85.6	27.7	-59.2	0.70	2.3
Management						
Conventional	64.5 (b)*	80.5	29.5	-59.2	0.69	2.3
Ecological	72.5 (a)*	87.0	32.0	-62.9	0.72	2.3

*Letters in parenthesis indicate a significant difference at $P<0.10$

Conclusion

Diversification beyond a two-year rotation did not improve spring wheat yield, however pea may yield higher when planted every third or fourth year compared to planting every other year. Ecological management practices increased yields of pea, but decreased yields of spring wheat, most likely due to a delayed planting date. Results from the transition phase of this long-term study suggest that increased level of rotation diversification in wheat and pea and ecological management in pea improve yield, in part through improved N use efficiency.

Marandu palisadegrass fertilized with nitrogen forms and sulphur rates: productive responses

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Abstract

In the present glasshouse work it was aimed to evaluate changes in the productive attributes of Marandu palisadegrass (*Brachiaria brizantha* cv. Marandu) in response to soil fertilization with nitrogen forms and sulphur rates. Soil fertilization treatments were the combination of four nitrogen forms (none, nitrate, ammonium+nitrate and ammonium) and four sulphur rates (none, 15, 30 and 45 mg/dm³). Treatments were arranged in a randomized complete block design, with four replications. Marandu palisadegrass was grown for 33 d after the transplanting, at which time number of leaves and tillers, leaf area and shoot dry matter were assessed. The productive response of Marandu palisadegrass fertilized with nitrogen and sulphur was affected by the nitrogen form supplied. Nitrate as nitrogen source strongly influenced the leaf area and shoot dry matter production of the forage grass. In general, grass production responses to sulphur rates seem to be more pronounced when the plants were fertilized with nitrate as nitrogen source.

Key Words

Soil fertilization; *Brachiaria brizantha*; nitrate; ammonium; forage grass

Introduction

Plant production is a result of growth and development processes and depends on nutrient availability in terms of forms and content in the soil. Among the nutrients, nitrogen along with phosphorus and potassium are largely applied worldwide through fertilizers (FAO 2008). Positive effects of nitrogen on crop productivity are notorious, especially on graminaceous plants (Xia and Wan 2008). The benefits of nitrogen supply on plant production are not restricted by the amount of nitrogen added to the soil, but nitrogen forms (ammonium and nitrate) are very important in promoting changes in plant morphogenesis (Walch-Liu *et al.* 2000; Rahayu *et al.* 2005). In addition, the nitrogen effects on plant growth can be changed by the sulphur availability in soil (Kalmbacher *et al.* 2005; Salvagiotti, *et al.* 2009), and probably plant response to nitrogen and sulphur interaction may change according to the supply of nitrogen form and sulphur rates. Thus, the objective was to evaluate changes in the productive attributes of Marandu palisadegrass (*Brachiaria brizantha* cv. Marandu) in response to soil fertilization with nitrogen forms and sulphur rates.

Methods

The experiment was conducted in a greenhouse located at Piracicaba, São Paulo (22°43'S; 47°38'W), Brazil, using 3.6-L pots filled with 5.5 kg of dried soil. The soil was collected from the surface 0-20 cm layer of a sandy soil classified as Entisol, characterized by low soil organic matter (14 g/kg) and low sulfate content (3.5 g/kg). Soil fertilization treatments were the combination of four nitrogen forms (none, nitrate, ammonium+nitrate and ammonium) and four sulphur rates (none, 15, 30 and 45 mg/dm³). Thus, the 16 treatments evaluated were: N₀ – S₀; N₀ – S₁₅; N₀ – S₃₀; N₀ – S₄₅; Nitrate – S₀; Nitrate – S₁₅; Nitrate – S₃₀; Nitrate – S₄₅; Ammonium – S₀; Ammonium – S₁₅; Ammonium – S₃₀; Ammonium – S₄₅; Ammonium nitrate – S₀; Ammonium nitrate – S₁₅; Ammonium nitrate – S₃₀; and Ammonium nitrate – S₄₅. Nitrogen forms were managed to apply nitrogen at 300 mg/dm³. The ammonium-N to nitrate-N ratio in the treatment ammonium nitrate was 30:70%. The ammonium-containing treatments received 20% of the total nitrogen through the nitrification inhibitor dicyandiamide (DCD). Treatments were arranged in a randomized complete block design with four replications. Nitrogen and sulphur were provided by the analytical reagents: Ca(NO₃)₂; NH₄Cl; and CaSO₄·2H₂O.

Taking into consideration the nutritional requirements of Marandu palisadegrass, liming was done with the objective of increasing soil base saturation to 50% by the application of CaCO₃ and MgCO₃. Basal fertilization with macronutrients for the establishment of Marandu palisadegrass were: phosphorus (P) = 200 mg/dm³; potassium (K) = 250 mg/dm³ and magnesium (Mg) = 50 mg/dm³, provided through KH₂PO₄ and MgCl₂·6H₂O. Additional amounts of calcium were applied as CaCl₂·6H₂O to equilibrate that supplied by nitrogen and sulphur sources in all treatments. Micronutrients as boron, copper, zinc and molybdenum were

supplied before grass planting with the following sources and amounts: $\text{H}_3\text{BO}_3 = 1.5 \text{ mg/dm}^3$; $\text{CuCl}_2 \cdot 2\text{H}_2\text{O} = 2.5 \text{ mg/dm}^3$; $\text{ZnCl}_2 = 2.0 \text{ mg/dm}^3$ and $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O} = 0.25 \text{ mg/dm}^3$.

Marandu palisadegrass seeds were germinated on a sterile sand medium. After 10 d, the seedlings were transferred to the soil in the pots (transplanting), and five grass plants were grown per pot. Irrigation was performed to maintain the soil water content around 80% of field capacity. Plant shoots were harvested 33 d after the transplanting. Plants were cut up to 4 cm above the soil and the above-ground material (shoot) was dried in a forced air oven at 65°C until constant mass. At the harvesting time, the number of tillers and leaves and leaf area of plants were also quantified. Leaf area was determined by using a leaf area machine model LI 3100 (LI-COR, NE, USA).

Results

The number of leaves of Marandu palisadegrass did not change with the supply of nitrogen and sulphur by soil fertilization (Figure 1a). On the other hand, the number of tillers was affected by nitrogen fertilization, in terms of quantity and nitrogen forms, and also by sulphur supply (Figure 1b). In general, increasing the sulphur availability to the plants resulted in more tillers produced.

The morphology of Marandu palisadegrass leaves was greatly influenced by the nitrogen forms used in soil fertilization (Figure 1c). Plants supplied with nitrate had a larger leaf area, enhancing the area of light interception (Akmal and Janssens 2004). Similar results have been reported by Walch-Liu *et al.* (2000) for tobacco plants grown in nutrient solution, where the authors found that leaves of plants treated with ammonium as nitrogen source presented 50% reduction in the number of cells and a 30% reduction in cell size, when compared with nitrate-fed tobacco plants.

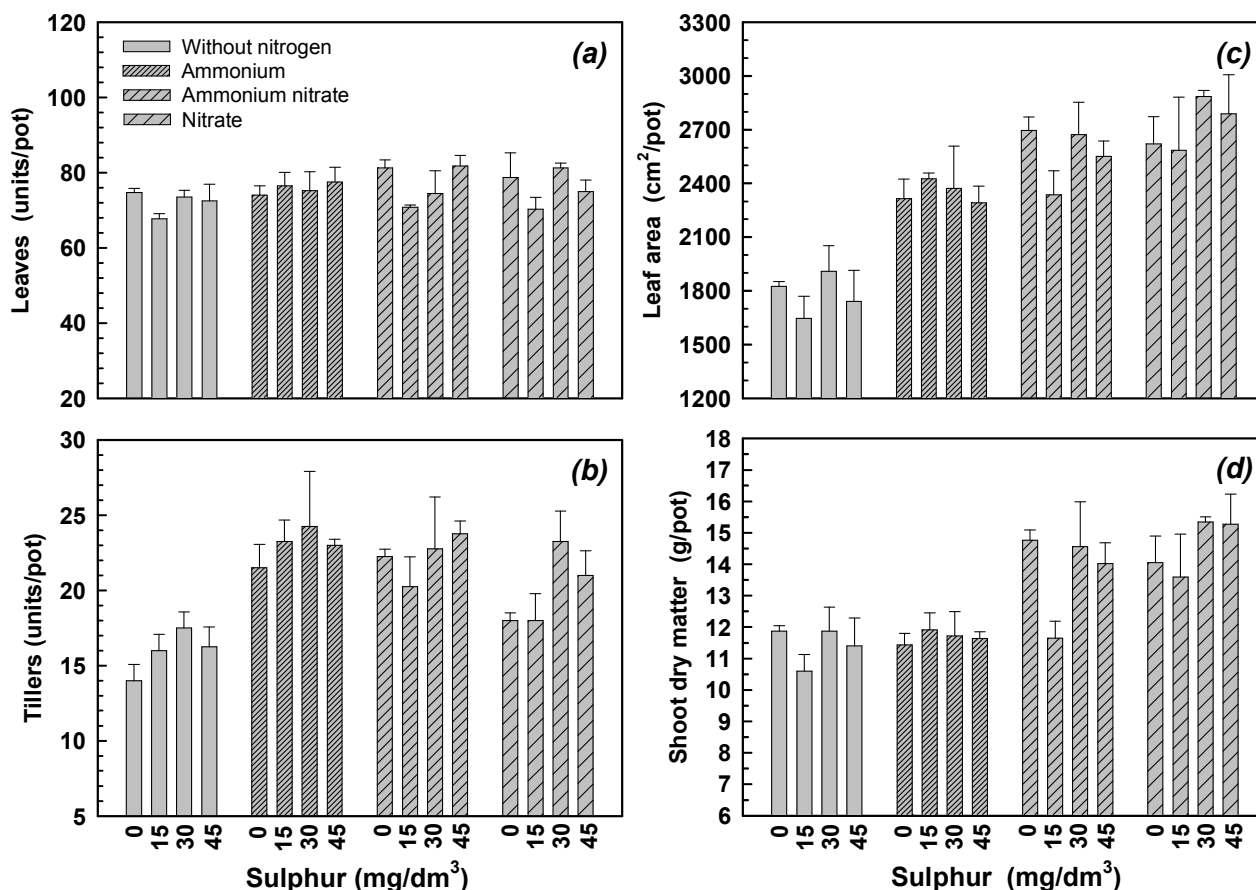


Figure 1. Leaves (a), tillers (b), leaf area (c) and shoot dry matter (d) production of Marandu palisadegrass fertilized with nitrogen forms and sulphur rates.

Conversely to the number of tillers and leaf area, the shoot dry matter production of Marandu palisadegrass was unaffected by the supply of nitrogen in the ammonium form (Figure 1d). Actually, only nitrogen as nitrate or ammonium mixed with nitrate showed increasing Marandu palisadegrass shoot dry matter. Possibly, plants growing in a medium with high ammonium availability may have impaired the shoot dry matter production through the effect of ammonium toxicity (Marschner 1995). Comparing plants fed with ammonium or nitrate solely, it seems that the effects of additional sulphur are more pronounced when the forage plants were fed with nitrate as nitrogen source (Figure 1b, 1c and 1d). These results agree with previous studies (Migge *et al.* 2000; Prosser *et al.* 2001), which postulated that S-deprived plants fertilized with nitrate showed decreased nitrate reductase activity.

Conclusions

The productive response of Marandu palisadegrass fertilized with nitrogen and sulphur depends on the nitrogen form. Nitrate as nitrogen source is closely related to leaf area and shoot dry matter production. In general, grass production responses to sulphur rates seems to be more pronounced when the plants are fertilized with nitrate-containing fertilizers.

Acknowledgements

To the State of São Paulo Research Foundation (FAPESP) and the Brazilian National Council for Scientific and Technological Development (CNPq) for the research financial support and for providing scholarship to the authors.

References

- Akmal M, Janssens, MJJ (2004) Productivity and light use efficiency of perennial ryegrass with contrasting water and nitrogen supplies. *Field Crops Research* **88**, 143-155.
- FAO (2008) "Current world fertilizer trends and outlook to 2011/2012" (FAO: Rome)
- Kalmbacher RS, Ezenwa IV, Arthington JD, Martin FG (2005) Sulfur fertilization of Bahiagrass with varying levels of nitrogen fertilization on a Florida Spodosol. *Agronomy Journal* **97**, 661-667.
- Marschner H (1995) Mineral nutrition of higher plants. (Academic Press: London)
- Migge A, Bork C, Hell R, Becker TW (2000) Negative regulation of nitrate reductase gene expression by glutamine or asparagines accumulating in leaves of sulfur-deprived tobacco. *Planta* **211**, 587-595.
- Prosser IA, Purves JV, Saker LR, Clarkson DT (2001) Rapid disruption of nitrogen metabolism and nitrate transport in spinach plants deprived of sulphate. *Journal of Experimental Botany* **52**, 113-121.
- Rahayu YS, Walch-Liu P, Neumann G, Römheld V, von Wirén N, Bangerth F (2005) Root-derived cytokinins as long-distance signals for NO₃⁻ induced stimulation of leaf growth. *Journal of Experimental Botany* **56**, 1143-1152.
- Salvagiotti F, Castellarin JM, Miralles, DJ, Pedrol, HM (2009) Sulfur fertilization improves nitrogen use efficiency in wheat by increasing nitrogen uptake. *Field Crops Research* **113**, 170-177.
- Walch-Liu P, Neumann G, Bangerth F, Engels C (2000) Rapid effects of nitrogen form on leaf morphogenesis in tobacco. *Journal of Experimental Botany* **51**, 227-237.
- Xia J, Wan S (2008) Global response patterns of terrestrial plant species to nitrogen addition. *New Phytologist* **179** 428-439.

Limited movement of fertiliser-derived Mg and K through volcanic ash and alluvial clay soils of Papua New Guinea

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Abstract

Crop symptoms of K and Mg deficiency are common on the coastal plains of Papua New Guinea. It was hypothesised that fertiliser uptake efficiency in oil palm is limited in these environments due to leaching loss resulting from high rainfall and high soil exchangeable Ca contents. Two field experiments were carried out on volcanic ash soils to determine the effect of fertiliser type (MgSO_4 , MgO or MgCO_3) on movement of Mg. In one trial the fertilisers were applied to 36-palm plots over a period of 3 years before soil sampling. In the other trial the fertilisers were applied evenly over 4 m² plots and the soil was sampled after 42 days and 1 year. A third field experiment, in which various rates of K fertiliser had been applied to an alluvial clay soil over a period of 13 years (36-palm plots), was sampled to determine the depth to which K had moved. Concentration profiles and mass balances showed that neither Mg nor K moved deeper than 0.6 m depth in any of the trials. In the K trial, approximately half of the fertiliser-derived K was fixed in non-exchangeable form. Results suggest that loss of K or Mg by leaching is not of concern in these environments.

Key Words

Exchangeable cations, K fixation, kieserite, magnesium carbonate, magnesium oxide, oil palm

Introduction

On the coastal plains of Papua New Guinea, symptoms of both K and Mg deficiencies occur across a range of crop species. Symptoms of both K and Mg deficiencies are widespread in areas of West New Britain and Oro Provinces with recent volcanic ash soils, whereas symptoms of K deficiency are common on alluvial clays of Milne Bay Province and clay soils on raised coral in New Ireland Province (Bleeker 1983). In the areas with K deficiency symptoms, crop responses to muriate of potash (KCl, hereafter referred to as MOP) are generally large, but the proportion of applied K actually taken up (uptake efficiency), is generally unknown. In the case of Mg, responses to kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$) have been rare on volcanic ash soils, despite the presence of symptoms consistent with deficiency, and good responses in Mg-deficient crops elsewhere (Turner 1981). The deficiencies of K, and possibly also Mg, are presumably largely due to the high ratios of exchangeable Ca:K and Ca:Mg in all those soils (Bleeker 1983) rather than low cation exchange capacity (CEC). In addition, high ratios of Mg:K may contribute to K deficiencies in the alluvial clay soils. Because of the high rainfall and high content and generation of exchangeable Ca from rapidly weathering minerals in these soils, it was thought that K and Mg applied as soluble fertilisers might rapidly leach out of the root zone, leading to low uptake efficiency of K and lack of response to soluble Mg fertiliser. In this work we set out to measure a) the amount of leaching loss of Mg from a volcanic ash soil of West New Britain to which kieserite or less soluble forms of Mg fertiliser had been applied, and b) the fate of fertiliser-applied K in a long-term fertiliser trial in oil palm on alluvial clay in Milne Bay.

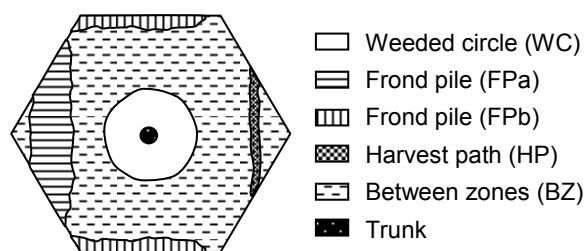
Methods

Trial 502: K fertiliser trial on alluvial clay in Milne Bay

The fate of fertiliser-applied K was measured in Trial 502. The area has an annual average rainfall of approximately 2,200 mm, and the well-structured smectitic clay soils have high CEC (35-47 cmol+/kg throughout top 1 m), dominated by Ca (20-32 cmol+/kg) and Mg (11-18 cmol+/kg). The trial is a complete factorial design, with sulphate of ammonia (SOA) applied at 0, 2, 4 or 6 kg/(palm.year), MOP applied at 0, 2.5, 5.0 or 7.5 kg/(palm.year), triple superphosphate applied at 0 or 2 kg/(palm.year), and empty fruit bunches (EFB) at 0 or 300 kg/(palm.year). The soil surface of the plantation can be classified into surface management zones (Figure 1). Fertiliser is applied by hand, with some zones, usually the BZ and FP zones, receiving more than others. Palms had been planted in 1986 at a density of 127 palms/ha, treatments commenced in 1995, and soils were sampled in 2005-2006. Soil samples were taken from plots that had received MOP at zero or 7.5 kg/(palm.year) and the highest rate of SOA. Auger samples were taken in a grid pattern covering the 4 palm units (Figure 1) in the centre of each plot (12 holes in WC, 7 in FPa, 5 in FPb

and 39 in BZ) to a depth of 1.4 m at depth increments of 0.2 m, and combined for each depth, zone and plot combination. Care was taken to prevent mixing of soil from different depths.

Figure 1. Surface management zones in the fertiliser trials. The hexagon, whose perimeter is defined by the midpoint between adjacent palms, is a 'palm unit', the repeating unit in oil palm plantations. The width of the palm unit, which equals the distance between palm centres, is approximately 9.0 to 9.8 m (at spacings of 143 and 120 palms/ha, respectively).



Trial 145: Mg fertiliser trial on volcanic ash soil at Walindi, West New Britain

Kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$) is the most commonly used form of Mg fertiliser, but as there were concerns about its solubility and possible loss by leaching, Trial 145 was established to compare different forms of Mg fertiliser. The site has approximately 3,900 mm annual rainfall and clayey volcanic ash soil, with the soil (0-0.2 m depth, mean of all 48 plots) having pre-treatment pH_{water} of 5.7 and effective CEC of 11.2 cmol+/kg, comprised of 7.1, 1.5, 1.9, 0.2 and 0.5 cmol+/kg exchangeable Ca, Mg, K, Na and acidity, respectively. Anion exchange capacity was not measured, but at similar sites it has been measured at <0.1 cmol-/kg at soil pH. The treatments were application of kieserite, MgCO_3 , MgO , and a MgCO_3 - MgO mix at rates supplying Mg at 0, 0.34 or 0.68 kg/(palm.year). All plots received basal applications of N, and occasionally K and B fertiliser. Palms had been planted in 1999 at a density of 120 palms/ha, treatments commenced in 2004, and soils were sampled in 2007. Sampling was in the zone of fertiliser application, at depth increments of 0-0.01, 0.01-0.05, 0.05-0.1, 0.1-0.2, 0.2-0.4 and 0.4-0.7 m. The samples from 0-0.2 m were taken using a trowel and spade and the deeper ones were taken with an auger.

Trial 151: Mg leaching trial on volcanic ash soil at Dami, West New Britain

When sampling Trial 145 to determine the fate of added Mg, it was unclear exactly where the fertiliser had been applied and where to sample. Therefore, Trial 151 was established in a young plantation on a sandy volcanic ash soil in order to quantify Mg movement. The soil (0-0.1 m depth, mean of control plots) had pH_{water} of 6.2 and effective CEC of 12.8 cmol+/kg, comprised of 10.6, 1.8, 0.3 and 0.1 cmol+/kg exchangeable Ca, Mg, K and Na, respectively. Anion exchange capacity was negligible at soil pH. Mg fertilisers (same ones as in Trial 145) were spread evenly over the soil surface in 2x2 m plots (4 replicates) at rates supplying Mg at 0 or 56.5 g/m². That application rate was chosen as it approximates the rate applied to the fertilised zone in commercial practice. The plots were sampled down to 1.5 m (auger holes in central 1 m²) when cumulative rainfall reached 745 mm (after 42 days) and 2,500 mm (after 1 year).

Soil analyses and solute transport modelling

Soil samples from all trials were analysed for exchangeable cations by compulsive exchange (Gillman and Sumpter 1986). In Trial 502, additional analyses were: non-exchangeable plus exchangeable K using tetraphenyl borate (TPB) extraction (Cox *et al.* 1996); and bulk density in selected samples. In Trial 151, additional analyses were; sulphate-S throughout the profile; forms of Mg in the 0-0.1 m depth layer, measured by sequential extraction (Uzo and Melsted 1972) and X-ray fluorescence (total Mg); bulk density; saturated hydraulic conductivity; water retention curves; and adsorption isotherms for K and Mg. The latter three analyses were carried out in order to facilitate solute transport modelling using HYDRUS-1D (Simunek *et al.* 1998).

Results

K movement through alluvial clay soil (Trial 502)

Of the K that had been applied in the previous 13 years and remained in the soil, most was in the top 0.2 m, and none was detected below 0.6 m (Figure 2). In the K-fertilised soil, TPB-K content was about double that of exchangeable K and followed a very similar pattern with depth. This means that the amount of non-exchangeable K was approximately equal to the amount of exchangeable K. By contrast, the ratio of non-exchangeable K to exchangeable K was much higher in the soils that received no K fertiliser (data not shown). The amount of fertiliser-applied K in the soil was calculated by subtracting the mean amount of TPB-K in the plots with no MOP applied from that in the plots that had had MOP applied. The total amount of fertiliser-applied K in the soil was 3,564 kg/ha. The amount of K sequestered and exported can also be

calculated from trial data or other estimates. The amount of K in standing biomass at the time of sampling was estimated at 808 kg/ha, and the amount estimated to have been exported in fruit bunches over the course of the trial was 1,690 kg/ha. This comes to a sum of 6,062 kg/ha, which is remarkably close to the amount of fertiliser that had been applied (6,191 kg/ha). Therefore, there appears to have been no significant loss of K from the site in runoff or leaching. Presumably most of this K will be available for uptake, although K in non-exchangeable form is only likely to become available if exchangeable concentrations drop sufficiently.

Mg movement through volcanic ash soils (Trials 145 and 151)

In Trial 145, Mg from the least soluble sources (MgCO_3 , MgO, and MgCO_3/MgO) remained in high concentrations near the surface (Figure 3). Indeed some lumps of MgO were still visible on the surface after 3 years. But surprisingly, exchangeable Mg concentrations were high in the top 0.01 m even where Mg had been supplied as soluble kieserite. In fact, it appears that no Mg had moved more than 0.2 m downwards in any of the treatments. Results were similar in the sandy soil of Trial 151; fertiliser-derived Mg was not detected below 0.2 m (Figure 4). By contrast, all of the sulphate applied in the kieserite treatment had moved out of the surface layer, and sulphate concentration increased with depth (Figure 5). While it was clear that the applied Mg was retained in the surface soil layers, exchangeable Mg did not account for all the Mg applied. Total Mg content of the control soil was 6,894 mg/kg, of which about one quarter was extracted in the fractionation procedure. Of the extractable Mg, most was in the tri-acid fraction in all plots, followed by exchangeable Mg. Most of the fertiliser-derived Mg ended up in the exchangeable fraction; 63, 74 and 63% of that applied as kieserite, MgO and MgCO_3 , respectively. In the kieserite and MgO plots some of the applied Mg was recovered in the acid-extractable fractions, but total recovery of applied Mg was only 75 and 77% respectively. On the other hand, in the MgCO_3 plot, 'recovery' of applied Mg was 151%. The reasons for the variations from 100% recovery are not yet clear, but may be due to spatial variability in application and movement of Mg. Results presented here are for the sampling at 42 days, but Mg had not moved significantly deeper after 1 year. Solute transport modelling using HYDRUS-1D satisfactorily simulated the movement of kieserite-derived Mg through the profile (Figure 4).

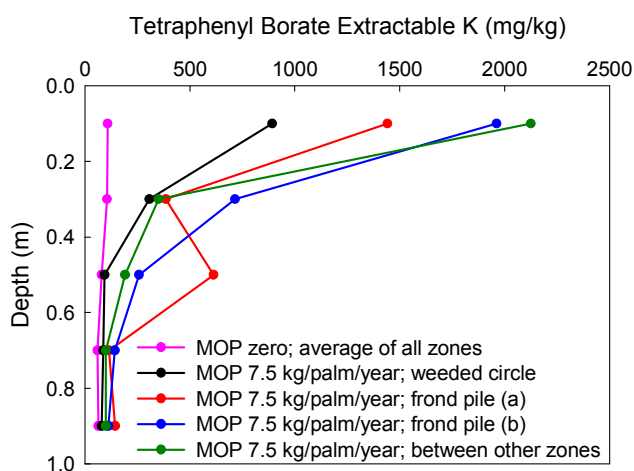


Figure 2. Tetraphenyl borate extractable K content of soil in plots to which MOP had been applied or not over 13 years (Trial 502). Values are means of 4 replicate plots.

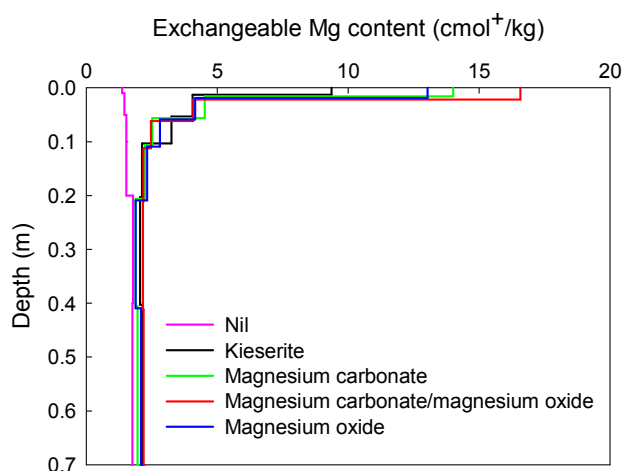


Figure 3. Distribution of exchangeable Mg with depth in the zone of fertiliser application in plots to which various forms of Mg fertiliser had been applied or not over 3 years (Trial 145). Values are means of 4 replicate plots. Concentrations in the +Mg treatments are 'normalised' so that the total amount of Mg in the profiles equals the average amount in all +Mg plots. This was done to obtain a comparative picture of distribution with depth, removing variability in actual values due to uneven distribution of fertiliser.

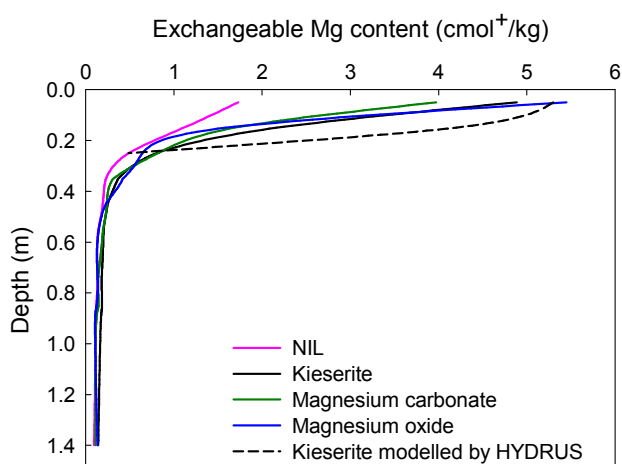


Figure 4. Exchangeable Mg content of plots to which one application of Mg fertiliser (various forms) had been made 42 days (and 745 mm rainfall) earlier (Trial 151). The dashed line shows concentration modelled using HYDRUS-1D.

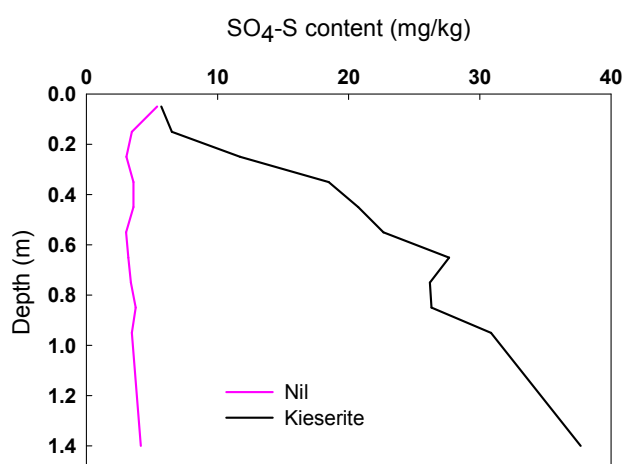


Figure 5. Concentration of sulphate-S in plots to which kieserite had been added or not 42 days (and 745 mm rainfall) earlier (Trial 151).

Conclusion

Despite high rainfall and high exchangeable Ca contents, fertiliser-applied Mg and K did not move below the top 0.6 m of the soils examined. The soils had sufficient CEC to retain all the applied Mg and K, even the sandy volcanic ash soil examined. In the volcanic ash soil, most of the fertiliser-derived Mg was retained in exchangeable form. In the alluvial clay, approximately half of the fertiliser-derived K retained in the soil was fixed into non-exchangeable forms. Leaching loss of K or Mg is therefore not of concern on these soils.

Acknowledgments

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References

- Bleeker P (1983) Soils of Papua New Guinea. (CSIRO and ANU Press: Canberra)
- Cox AE, Joern BC, Roth CB (1996) Non exchangeable ammonium and potassium determination in soils with a modified sodium tetraphenylboron method. *Soil Science Society of America Journal* **60**, 114-120.
- Gillman G, Sumpter EA (1986) Modification of the compulsive exchange method for measuring exchange characteristics of soils. *Australian Journal of Soil Research* **24**, 61-66.
- Simunek J, Sejna M, van Genuchten MTh (1998) *The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media. Version 2.0*, IGWMC - TPS - 70, International Ground Water Modeling Center, Colorado School of Mines, Golden, Colorado, 202pp.
- Turner PD (1981) Oil Palm Diseases and Disorders. (Oxford University Press: Oxford)
- Uzo Mokwunye A, Melsted SW (1972) Magnesium forms in selected temperate and tropical soils. *Soil Science Society of America Proceedings* **36**, 762 -764.

Nitrogen and sulfur fertilization for a Signal grass pasture: forage yield, nutritional status and some soil fertility attributes in a rainy season

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Abstract

Fertilizer application is required for pasture establishment and productivity, and the sulfur supply is not always considered when grasses are fertilized with nitrogen. The objectives were to evaluate the effects of combined nitrogen and sulfur rates in a degrading Signal grass (*Brachiaria decumbens*) pasture during a rainy season, by measuring forage yield, nitrogen and sulfur concentrations, N:S ratio and SPAD values in the diagnostic leaves, and some soil fertility attributes. The experiment was carried out on an eight years old Signal grass pasture, which was established on an Entisol. Five nitrogen rates and five sulfur rates were combined in a 5x5 fractionated factorial, in a randomized block design, with three replications. Nitrogen and sulfur combinations resulted in significant changes in the Signal grass productivity and SPAD values in the grass during the rainy season. Both nitrogen and sulfur concentrations in the diagnostic leaves were increased by nitrogen and sulfur rates, respectively. Sulfur deficiency was found in the diagnostic leaves of the grass that did not receive sulfur fertilizer. Nitrogen rates reduced soil pH and exchangeable potassium and magnesium, whereas exchangeable calcium did not change.

Key Words

Brachiaria decumbens; Forage grass; Leaf diagnosis; Pasture fertilization; SPAD.

Introduction

Lack of nutrients, inadequate management of pastures, and inappropriate cultural practices are responsible for pasture degradation. These inappropriate management practices can also result in severe environmental consequences, such as reduced soil fertility, decrease in water use efficiency, decline in plant biomass production, reduced soil coverage, decreased soil biological activity, and increased soil compaction and soil erosion (Syers *et al.* 1996). Low nitrogen availability has been identified as a major cause of degradation of tropical pastures (Werner 1994), and the constant removal of forage without proper supply of nutrients extracted by plants emphasizes the problems of rangeland degradation. The combined application of nitrogen with sulfur has proved to be effective in maximizing the leaf area and the production of dry matter of grasses, and the balance between the amounts of these two nutrients in the soil and the plant provides adequate growth and nutritional status of the plant (Dijkshoorn and van Wijk 1967; Bonfim-Silva and Monteiro 2006; Batista and Monteiro 2008). The objectives of this research were to determine the effects of nitrogen and sulfur rates on forage yield, mineral nutritional status and some soil fertility attributes, when applied to a degrading Signal grass pasture during a rainy season.

Methods

The experiment was carried out in a farm (47° 57' 56" W and 22° 46' 30" S) located at Piracicaba, State of São Paulo, Brazil, during the 2005-2006 wet season. A Signal grass (*Brachiaria decumbens* Stapf.) pasture was established over eight years on an Entisol, did not receive any previous fertilization and was degrading. The experimental area (1800 m²) was isolated from the farm pasture, and each plot was 5m x 8 m. Dolomitic limestone (600 kg/ha) was applied to the soil surface prior to any fertilization. Phosphorus (P₂O₅ = 30 kg/ha) was supplied as triple superphosphate, potassium (K₂O = 30 kg/ha) as potassium chloride, and micronutrients as FTE Br-16 (30 kg/ha). Five nitrogen rates (0, 150, 300, 450 and 600 kg/ha/yr) and five sulfur rates (0, 15, 30, 45 and 60 kg/ha/yr) were combined in a 5x5 fractionated factorial (Littell and Mott 1975), in a randomized block design with three replications. Nitrogen was supplied as ammonium nitrate and sulfur as gypsum, and both products were split into three times during the rainy season (November 17, 2005; December 23, 2005 and January 28, 2006). Forage yield was measured at predetermined intervals of 35 days during the rainy season, which resulted in five field evaluations (December, 2005; January, 2006; March, 2006; April, 2006 and May, 2006). At each evaluation time, samples of plant shoots were taken within a wood frame of 1.00 m x 0.25 m (0.25 m²) placed in each plot, and plants were harvested at 5 cm from the soil surface. At the time of the third field evaluation (March 01, 2006) SPAD values were measured in the

second fully expanded leaf lamina, and the first and second fully expanded leaf laminae (diagnostic leaves) were collected. All plots were grazed by beef cattle just after plant measurements and sampling. Plant samples (both above ground mass and the two fully expanded leaf laminae) were put in a paper bag, placed in an oven (65° C) to obtain constant dry weight, followed by weighing. The samples of fully expanded leaf laminae were ground and taken to the laboratory for nitrogen (Kjeldahl method) and sulfur (turbidimetric method) determinations. Also the N:S ratio in the leaf laminae samples was calculated. Soil samples were taken at depths 0-10 and 10-20 cm at the end of the rainy season. Soil determinations were pH in CaCl₂ and exchangeable K, Ca and Mg (after extraction by ion exchange resin). Statistics were performed through the use of the Statistical Analysis System (SAS 1999), and the significance level was 5% in all statistical tests. The analysis of variance (F test) was performed first, then, the RSREG procedure (for response surface) was used when the nitrogen x sulfur interaction was significant, and GLM procedure (for the first and second order regression models) was adopted when that interaction was not significant.

Results

Signal grass forage yield during the six-month wet season ranged from 13,447 to 25,142 kg/ha, depending on the nitrogen x sulfur interaction and the results fitted to a polynomial regression model (Figure 1). Such nitrogen x sulfur interaction was also observed by Bonfim-Silva and Monteiro (2006) for *Brachiaria decumbens*, Batista and Monteiro (2008) for *Brachiaria brizantha* cv. Marandu. In order to reach the highest forage yield it was necessary to supply nitrogen at 450 kg/ha/yr, associated with the higher sulfur rates (45 to 60 kg/ha/yr). No-nitrogen combined with no-sulfur resulted in about half the forage yield that was measured when both nutrients were supplied. The supply of sulfur, even proved to be necessary to increase forage yield, but only showed a clear beneficial effect when applied together with nitrogen. Also, Havlin *et al.* (2005) reported that an adequate supply of sulfur to the pasture increased the response of grasses to applied nitrogen and improved the efficiency of use of nitrogen. These results confirm the importance of balancing the supply of nitrogen and sulfur to achieve high productivity of grasses.

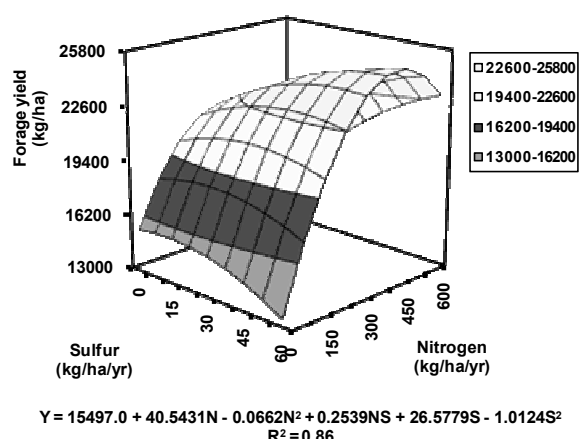


Figure 1. Signal grass forage yield in response to combined nitrogen and sulfur rates in the wet season.

The nitrogen x sulfur interaction was not significant for nitrogen and sulfur concentrations, and for N:S ratio in the diagnostic leaves of Signal grass collected at the third evaluation during the rainy season. However, nitrogen and sulfur concentrations in the diagnostic leaves were significantly changed by nitrogen and sulfur rates. Nitrogen concentration in the diagnostic leaves reached the maximum at the nitrogen rate of 462 kg/ha/yr (Figure 2a), whereas the maximum sulfur concentration occurred at the sulfur rate of 40 kg/ha/yr (Figure 2b). Both nitrogen and sulfur rates had significant linear effects on the N:S ratio in the grass diagnostic leaves (Figure 2c). Low sulfur concentration and high N: S ratio in diagnostic leaves supported the sulfur deficiency identification in the grass not fertilized with sulfur. Nitrogen x sulfur interaction was significant for the SPAD values measured in the expanded leaf laminae at the same time of diagnostic leaves sampling. Nitrogen supplied at 450 to 600 kg/ha/yr associated with sulfur application of 45 to 60 kg/ha/yr resulted in the maximum SPAD values (Figure 2d). The changes in the nitrogen and sulfur relationships have been described for other grasses (Wang *et al.* 2002; Gierus *et al.* 2005).

The nitrogen x sulfur interaction was not significant for the soil pH, and exchangeable Ca, Mg and K measured at the end of the wet season, but significance was found for the nitrogen rates on three of these four soil attributes. Soil pH values varied from 5.2 to 4.7 at a 0-10 cm depth (Figure 3a) and from 5.0 to 4.5 at the

10-20 cm depth (Figure 3b). The decrease in soil pH (which in this case was about 0.5 unit) with increasing nitrogen fertilization is a well-known consequence of hydrogen release when ammonium is applied to the soil (Havlin *et al.* 2005). Exchangeable Ca at 0-10 or 10-20 cm soil depth did not change significantly with the treatments. On the other hand, both exchangeable K (Figure 3c) and Mg (Figure 3d) were linearly reduced as the nitrogen rates were increased. These decreases in soil exchangeable K and Mg may be a result of their removal (and leaching) from the exchangeable sites in the soil through the action of ammonium ion and their higher extraction by plants with increased yield.

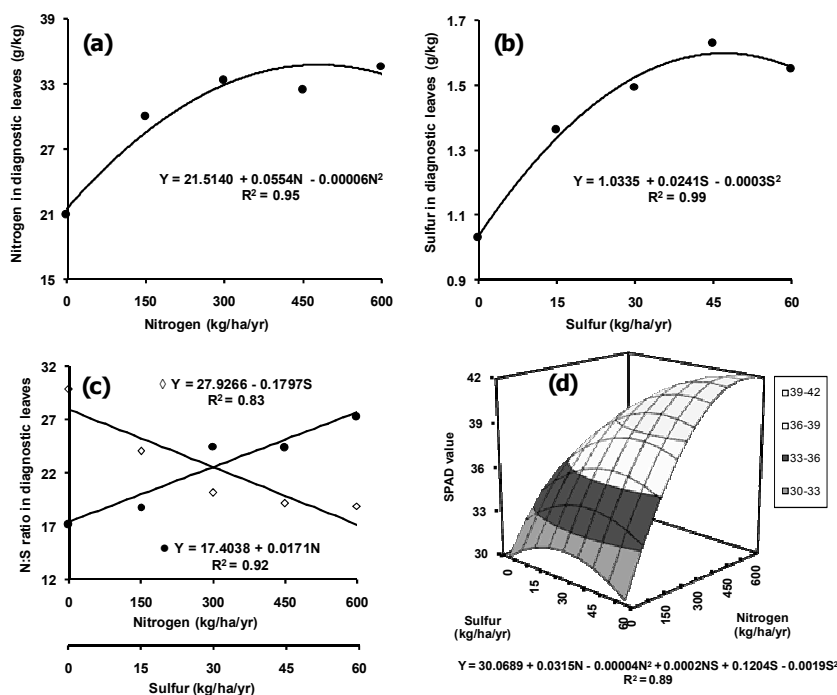


Figure 2. Nitrogen concentration (a), sulfur concentration (b), N:S ratio (c) and SPAD value (d) in the diagnostic leaves of Signal grass, as related to nitrogen and sulfur fertilization and determined at the third evaluation during the rainy season.

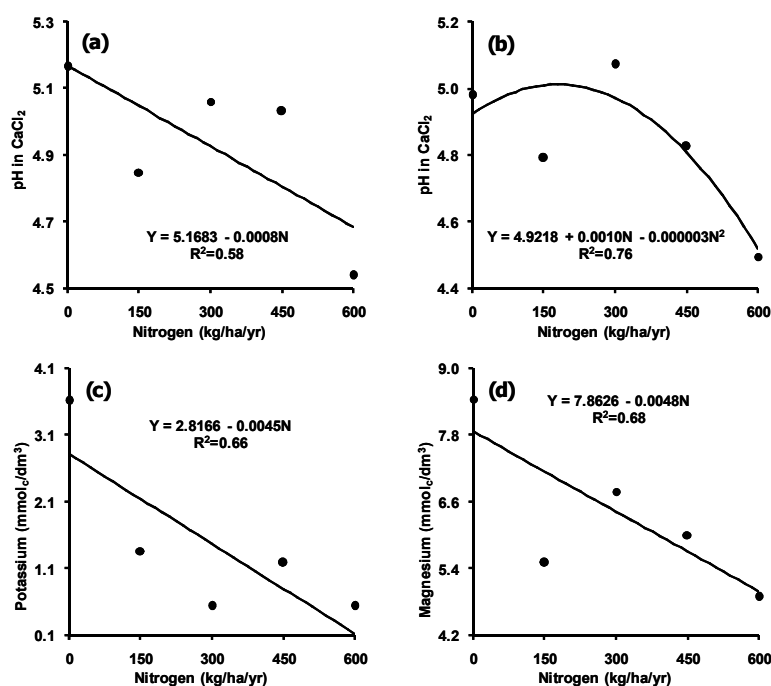


Figure 3. Soil pH at a depth of 0-10 cm (a), pH at a depth of 10-20 cm (b), potassium at a depth of 0-10 cm (c) and magnesium at a depth of 10-20 cm (d) from soil surface in the end of first rainy season of the experiment.

Conclusions

Nitrogen and sulfur combinations promoted the recovery of Signal grass productivity and changes in SPAD values during the rainy season. Nitrogen and sulfur fertilizations resulted in increases in these nutrients concentrations in diagnostic leaves. Sulfur deficiency was found in the grass that did not receive sulfur fertilization. Low depth soil pH and exchangeable potassium and magnesium were decreased by nitrogen fertilizations.

Acknowledgements

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References

- Batista K, Monteiro FA (2008) Nitrogen and sulphur on morphogenic characteristic of marandu palisadegrass replacing signal grass under degradation in a low organic matter soil *Brazilian Journal of Animal Science* **7**, 1151-1160.
- Bonfim-Silva EM, Monteiro FA (2006) Nitrogen and sulphur for productive characteristics of signal grass from degrading pasture area *Brazilian Journal of Animal Science* **4**, 1289-1297.
- Dijkshoorn W, van Wijk AL (1967) The sulfur requirements of plants as evidenced by the sulfur-nitrogen ratio in the organic matter: a review of published data. *Plant and Soil* **26**, 129-157.
- Gierus M, Jahns U, Wulfes R, Wiermann C, Taube F (2005) Forage quality and yield increments of intensive managed grassland in response to combined sulphur-nitrogen fertilization. *Acta Agriculturae Scandinavica. Section B-Soil and Plant Science* **55**, 264-274.
- Havlin JL, Tisdale SL, Beaton JD, Nelson WL (2005) 'Soil fertility and fertilizers: an introduction to nutrient management'. (New Jersey: Pearson Prentice Hall)
- Littell RC, Mott GO (1975) Computer assisted design and analysis of response surface experiments in agronomy. *Soil and Crop Society of Florida Proceedings* **34**, 94-97.
- Statistical Analysis System (1999) 'User's guide statistics: version 8.0 edition' (Cary)
- Syers JK, Lingard J, Pieri C, Ezcurra E, Faure G (1996) Sustainable land management for the semiarid and sub-humid tropics. *Ambio* **25**, 484-491.
- Wang S, Wang Y, Schnug E, Haneklaus S, Fleckenstein J (2002) Effects of nitrogen and sulphur fertilization on oats yield, quality and digestibility and nitrogen and sulphur metabolism of sheep in the Inner Mongolia Steppes of China. *Nutrient Cycling in Agroecosystems* **62**, 195-202.
- Werner JC (1994) Fertilization of *Brachiaria* spp. In 'Symposium on pasture management' (Eds AM Peixoto, JC Moura, VP Faria) pp. 209-266. (Piracicaba: FEALQ).

Nitrogen leaching from contrasting liquid fertilizers applied to three soils

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Abstract

In recent years, new liquid fertilizers have been formulated to slowly release nitrogen. However, little information is known about their nitrogen release when applied to different soils. In two, 56 day greenhouse experiments, mineral nitrogen and total Kjeldahl nitrogen (TKN) leaching curves were determined by applying either no fertilizer, urea, or three controlled release liquid fertilizers to three soils: sand, a mix of 90% sand and 10% peat moss, and a sandy clay loam. All fertilizers leached quickly through the sand soil with no differences in N leached. The least leaching occurred from fertilizers applied to the sandy clay loam. In the second half of EXP2, urea released the greatest TKN when applied to the sandy clay loam, but not when applied to the other two soils. Controlled release liquid fertilizers influenced both mineral nitrogen and TKN leaching in different soils.

Key Words

Sandy clay loam, urea polymers, urea-ammonium nitrate, total Kjeldahl nitrogen

Introduction

Nitrogen (N) is the most essential turfgrass nutrient (Beard 1973). Turfgrass managers have often applied urea because of its low cost and for the quick turfgrass green up that urea provides (McCarty *et al.* 2003). However because it is a soluble N source, what is not utilized by the turfgrass can potentially leach rapidly through the soil profile with subsequent irrigations and rainfall and can potentially contaminate receiving waters (Duncan *et al.* 2009). In addition, urea N can be lost by ammonia volatilization under optimal conditions (Carrow *et al.* 2001). Granular controlled release fertilizers have been documented to release N over a long period of time, allowing N to be continuously available to the plant, and resulting in uniform long term quality, and reducing fertilizer application frequency and the leaching potential to receiving waters (Carrow 1997; Cisar *et al.* 2005; Hummel 1989; Soldat *et al.* 2008).

Controlled release liquid fertilizers (CRLF) are relatively new compared to granular products. The main advantage of CRLF is that they can be tank mixed and applied with other chemicals or injected into the irrigation system. Eliminating the need to apply fertilizer separately may reduce time, financial, and labour resources. In addition, liquid fertilizers are not removed from close-cut turfgrass during mowing. These advantages have made CRLF appealing not only for high-end managed turfgrass, but also for sod production. Unlike their granular counterparts, relatively little information is known on the N release characteristics of CRLF, and even less on their N release from various soil types. The objective of this research was to determine N leaching from three CRLF and soluble urea from three contrasting soils.

Methods and Materials

Two greenhouse experiments (EXP1: April 09 – June 02, 2008, and EXP2: June 16-August 08^h, 2008) were conducted for 56 days each at the Clemson University Pee Dee Research and Education Center in Florence, South Carolina, USA, 29506. Leaching columns (10 cm in dia., 15 cm length) were constructed from PVC tubing with end caps. Plastic screening was glued to the bottom of the PVC. A 6.4 mm hole was drilled into the bottom of the end caps to allow for drainage and then glued to the screened end of the PVC tube. Wood racks supported the leaching columns and suspended them 15 cm off the bench. Plastic bowls were placed under each column to collect leachate. Each column was filled with one of the three soils to 2.5 cm from the top lip: size 45 sand (SAND), 90:10, size 45 sand:peat mix (MIX), and a sandy clay loam (SCL). The SCL was obtained from the Bt horizon of Lynchburg series soil (fine-loamy, siliceous, semiactive, thermic Aeric Paleaquult, Soil Survey Staff, NRCS 2009). Prior to experiment initiation, one litre of deionized water was applied to the soils and allowed to drain to achieve field capacity. The leachate was collected to determine baseline N. On the following day, one of five liquid fertilizers (FERT) was randomly applied on the surface of each column at a rate of 0.50 t N/ha (390 mg N per column): None (NONE), GP30 (22-0-0, 6% N from UAN, 94% N from urea polymers), GP44 (28.2-0-0, 71.8% N from UAN, 28.2% N from urea polymers),

GP83 (20-0-0, 81.2% N from urea, 18.8% N from urea polymers) and UREA (46.6-0-0, 100% urea). The UREA was included as a non-controlled release liquid standard. For EXP1, the columns were irrigated directly after fertilizer applications with 8.5 mm of water. The columns received 8.5 mm of water every M-W-F to simulate irrigation events. On Days 7, 21, 35, and 49, the lysimeters received 25 mm of water to simulate rain events. In EXP2, 12.7 mm of water was applied instead of 8.5 mm due to warmer temperatures resulting in drier soils and to ensure enough leachate could be collected for analysis. When leaching occurred, leachate was collected and the volume determined. Nitrogen release characteristics were determined by analysing the leachate for $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, and total Kjeldahl nitrogen (TKN) using continuous flow injection colorimetry (QuikChem methods 10-107-04-1-O, 10-107-06-01-B and 10-107-06-2-I). Mineral nitrogen (MN) was determined by summing $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$. The experimental design was a randomized complete block design with three replications ($n=45$). Data were analysed by two-way ANOVA using SAS software (SAS Institute 2003). When differences in treatment means were determined to be significant, means were separated using the Waller-Duncan's K-ratio test.

Results

Leaching during EXP1 was observed from columns only at pre-treatment, the first-week irrigations and after the 25 mm rain events. In comparison, during EXP2, additional leaching was observed on some irrigation dates following a rain event. On these days, the leachate volume was not always sufficient for all N analyses, and thus $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ were analysed first. If TKN was not determined due to insufficient sample volume, the analytical results from the previous leaching date were used to represent a worst case scenario.

The SOIL x FERT effect was significant for all leaching dates after treatment application for MN in EXP1, and for the majority of leaching dates for MN and TKN in EXP2 (Table 1a and b). Specific interactions varied by date. However on many dates the interaction resulted from fewer differences among fertilizer treatments from the SAND compared to the MIX and SCL (Tables 2 and 3). Perhaps the lack of differences for the fertilizers in the SAND may be explained by greater porosity and lower volumetric water holding capacity common to soils without organic material and finer particles such as found in the MIX and SCL.

Table 1. Table of significance for mineral nitrogen ($\text{NO}_3\text{-N} + \text{NH}_4\text{-N}$) and TKN over the two experiments.

	Day 0	Day 1	Day 3	Day 5	Day 7	Day 9	Day 11	Day 21	Day 23	Day 35	Day 49	Day 51	Total
(a) MN													
EXP1													
SOIL	***†	***	***	---	**	---	---	***	---	***	***	---	**
FERT	ns	***	***	---	***	---	---	***	---	***	***	---	***
SOIL x FERT	ns	**	**	---	***	---	---	***	---	***	***	---	**
EXP2													
SOIL	***	**	**	***	***	ns	*	---	ns	***	***	***	***
FERT	ns	***	***	***	***	**	***	---	***	***	***	***	***
SOIL x FERT	ns	***	***	***	***	ns	***	---	ns	***	***	***	***
(b) TKN													
EXP1													
SOIL	***	ns	ns	---	ns	---	---	ns	---	***	***	---	ns
FERT	ns	ns	***	---	***	---	---	***	---	***	**	---	***
SOIL x FERT	ns	ns	ns	---	ns	---	---	ns	---	***	*	---	ns
EXP2													
SOIL	ns	***	***	***	***	ns	***	---	***	***	***	***	***
FERT	ns	**	*	***	***	ns	***	---	***	***	***	***	***
SOIL x FERT	ns	ns	**	**	ns	ns	**	---	ns	***	***	**	ns

†ns, *, ** and *** = $P>0.10$, $P<0.10$, $P<0.05$, and $P<0.01$ respectively. --- = no leaching occurred.

Mineral nitrogen

Before fertilizer was applied in EXP1, similar MN was leached from the SCL and MIX soils (0.26 and 0.24 mg respectively), which was greater than MN leached from the SAND (0.02 mg, Table 2). In EXP2, before fertilizer was applied, greater MN leached from the SCL soil (1.03 mg) compared to the SAND (0.74 mg), with both greater than from the MIX (0.52 mg, Table 1a). The greatest MN leached was after rain events (Tables 2 and 3). All fertilizers resulted in MN leaching on the first leaching date after fertilizer application (Tables 2 and 3). GP30 and GP83 resulted in more uniform MN release in the SCL and MIX soils (Tables 2 and 3). In both experiments and for all soils, applying GP44 resulted in the greatest MN leached on many days and in total (Tables 2 and 3). The high MN leaching of GP44 can be attributed to the high percent of

UAN within the fertilizer. From Day 35 onward in EXP2, MN leached from the UREA treatment was greater than all other fertilizer treatments (Table 3). The high MN recovery from applying no fertilizer (NONE) to the SCL in EXP1 may be from soil organic mater N mineralization (Table 2).

Table 2. Mineral nitrogen (NH₄-N and NO₃-N) leached (in mg) from fertilizer sources for each soil over EXP1.

(a) SAND	Day 0	Day 1 [†]	Day 3	Day 7 [†]	Day 21 [†]	Day 35 [†]	Day 49 [†]	Total
GP44	0.00	0.34a	0.09	153a	0.12	0.04	0.04	154a
GP83	0.01	0.13b	0.01	4.69b	0.05	0.03	0.01	4.90b
GP30	0.02	0.20b	0.01	3.32b	0.09	0.01	0.01	0.19b
Urea	0.01	0.07b	0.01	0.61b	0.02	0.01	0.02	0.74b
None	0.00	0.01b	0.00	0.03b	0.01	0.00	0.02	0.07b
Significance	ns	**	ns	***	ns	ns	ns	***
(b) MIX								
GP44	0.23	1.31a	0.24a	88.3a	1.58a	2.64a	2.48a	96.6a
GP83	0.20	0.49bc	0.03b	0.85b	0.57c	0.74b	1.41b	4.09b
GP30	0.30	0.62b	0.04b	0.83b	1.11b	2.87a	2.47a	7.95b
Urea	0.22	0.35bc	0.03b	0.56b	0.55c	0.50b	0.66c	2.66b
None	0.25	0.09c	0.01b	0.28b	0.09d	0.04b	0.08c	0.60b
Significance	ns	***	***	***	***	**	***	**
(b) SCL								
GP44	0.14	1.86a	0.45a	42.4a	1.46a	0.81ab	1.17ab	48.6a
GP83	0.19	0.86b	0.10bc	0.85b	0.82b	0.41b	0.51bc	3.56b
GP30	0.28	1.86a	0.19b	0.95b	1.64a	1.63a	1.81a	3.50b
Urea	0.33	0.23c	0.04bc	0.60b	0.25c	0.13b	0.31c	1.55b
None	0.37	0.05c	0.01c	0.10b	0.11c	0.08b	0.18c	0.54b
Significance	ns	***	***	*	***	***	***	***

[†] represents rain event (25 mm of water applied). All other days are irrigation days (8.5 mm of water applied). ns, *, ** and *** = P>0.10, P<0.10, P<0.05, and P<0.01 respectively.

Table 3. Mineral nitrogen (NH₄-N and NO₃-N) leached (in mg) from fertilizer sources for each soil over EXP2.

(a) SAND	Day 0	Day 1 [†]	Day 3	Day 5	Day 7 [†]	Day 9	Day 11	Day 21 [†]	Day 35 [†]	Day 49 [†]	Day 51	Total
GP44	0.77	0.26	18.4a	13.3a	50.9a	2.24	16.2b	1.68	2.92b	0.79	0.14	108a
GP83	0.67	0.15	0.54b	2.57b	11.9b	1.00	15.2b	2.28	1.74bc	0.87	0.07	37.0c
GP30	0.65	0.04	0.48b	2.67b	11.1b	0.52	18.4b	1.91	2.37b	0.65	0.08	38.9c
Urea	0.79	0.02	0.42b	2.18b	9.41b	0.00	30.3a	3.04	5.16a	0.63	0.02	52.0b
None	0.82	0.06	0.01b	0.01c	0.07b	0.01	0.21c	0.06	0.14c	0.11	0.07	1.52d
Significance	ns	ns	***	***	***	ns	***	ns	***	ns	ns	***
(b) MIX												
GP44	0.57	0.10	9.05a	8.83a	48.3a	2.95	33.4a	2.80	3.79ab	4.10a	2.26a	116a
GP83	0.51	0.23	0.18b	0.97b	4.77b	0.38	15.9b	2.52	5.67a	4.16a	1.29ab	36.2b
GP30	0.49	14.0	0.09b	0.94b	5.95b	0.34	11.5b	1.62	3.49b	2.95ab	0.74bc	28.3b
Urea	0.55	0.11	0.25b	0.63b	4.14b	0.43	8.09bc	2.59	4.54ab	4.35a	2.07a	27.7b
None	0.47	0.12	0.02b	0.03b	0.12b	0.59	0.23c	0.13	0.11c	0.07b	0.03c	1.91c
Significance	ns	ns	***	***	***	ns	***	ns	***	*	***	***
(b) SCL												
GP44	1.23	0.98a	1.45	2.86a	19.6a	1.40	28.5a	5.45a	9.77b	4.68c	1.50c	77.4a
GP83	1.06	0.13b	0.23	0.55b	4.42b	0.62	5.82b	1.90b	6.34c	10.3b	4.30b	35.7c
GP30	0.96	0.18b	0.26	0.66b	3.84b	0.41	6.48b	1.13b	3.52d	2.08cd	1.28c	20.8d
Urea	0.95	0.10b	1.55	0.55b	6.78b	0.20	7.60b	2.09b	12.6a	14.4a	5.53a	52.3b
None	0.95	0.06b	0.23	0.01b	0.08b	0.01	0.23b	0.09b	0.36e	0.39d	0.72c	3.13e
Significance	ns	***	ns	*	***	ns	***	***	***	***	***	***

[†] represents rain event (25 mm of water applied). All other days are irrigation days (12.7 mm of water applied). ns, *, ** and *** = P>0.10, P<0.10, P<0.05, and P<0.01 respectively.

Total Kjeldahl nitrogen

Before fertilizer was applied in EXP1, greater TKN leached from the SCL (0.76 mg) compared to the MIX (0.54 mg), with both greater than the SAND (0.23 mg, Table 1). Once fertilizer was applied, only FERT influenced TKN leaching until the last two leaching dates. As the experiment progressed, GP44 and GP30 resulted in the greatest TKN leaching, which were sometimes similar to other fertilizer treatments (Figure 1).

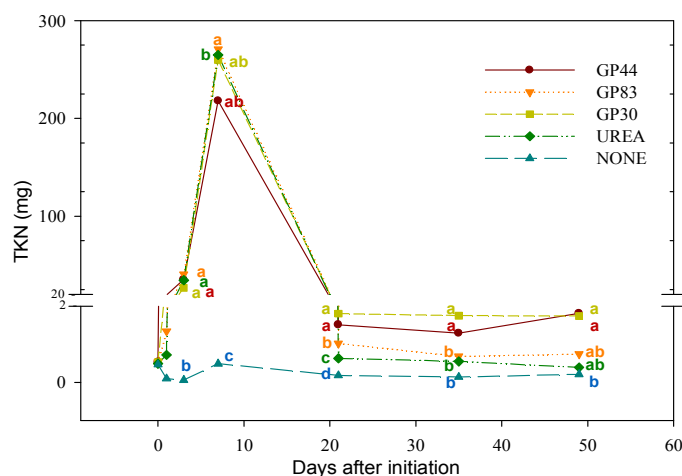


Figure 1. Total Kjeldahl nitrogen (TKN) leached from five fertilizer treatments over the EXP1. Means with the same letter within a column are not significantly different at the 0.10 significance level.

Pre-treatment TKN leachate from EXP2 was not influenced by any factor. Throughout EXP2 TKN leached was affected by SOIL and/or FERT but not their interaction (Table 1b): On Day7 and 23 of EXP2, TKN leached was greatest from SAND, the least from SCL, with the MIX always similar to the SAND (data not shown, Table 1b). Total TKN leached from SCL in EXP2 was approximately half of TKN leached from SAND and MIX (data not shown, Table 1b). On EXP2 days in which FERT influenced TKN leached (Table 1b), NONE resulted in the least amount of TKN losses. GP83, UREA, and GP30 had similar TKN leaching, which was less than GP44 (data not shown, Table 1b). The recovery differences between the soils in EXP2 may be explained by there being sufficient soil water for microbially mediated mineralization and immobilization.

In summary, the two CRLFs with high % urea polymers (GP30 and GP83) resulted in less than or similar MN and TKN leaching than the UREA. The CRLF with minimal % urea polymers (GP44) resulted in the most leaching.

References

- Beard JB (1973) *Turfgrass Science and Culture*. 642 p. Prentice Hall, Inc. Englewood Cliffs, N.J.
- Carrow, Robert N (1997) Turfgrass Response to Slow-Release Nitrogen Fertilizers. *Agron. J.* **89**, 491-496.
- Carrow RN, Waddington DV, Rieke PE (2001) *Turfgrass soil fertility and chemical problems*. Ann Arbor Press, Chelsea, MI. 400 p.
- Cisar JL, Snyder GH, Haydu JJ, Park DM, Williams KE (2005) An evaluation of nitrogen sources on bermudagrass color, clippings, and nitrogen release. *Int. Turfgrass Soc. Res. J.* **10**, 144-151.
- Duncan RR, Carrow RN, Huck M (2009) *Turfgrasses and Landscape Irrigation Water Quality – Assessment and Management*. CRC Press, Boca Raton, FL. 464 p.
- Hummel NW, Jr (1989) Resin-Coated Urea Evaluation for Turfgrass Fertilization. *Agron. J.* **81**, 290-294.
- McCarty LB, Rodriguez IR, Bunnell BT, Waltz FC (2003) *Fundamentals of Turfgrass and Agricultural Chemistry*. John Wiley & Sons, Inc. Hoboken, NJ. 376 p.
- SAS Institute Inc. (2003) *SAS/STAT User's Guide*, Version 9.1 Cary, North Carolina.
- Soldat DJ, Petrovic AM, Barlow J (2008) Turfgrass Response to Nitrogen Sources with Varying Nitrogen Release Rates. *Acta Hort. (ISHS)* **783**, 453-462.
- Soil Survey Staff, Natural Resources Conservation Service, USDA. Official Soil Series Descriptions [Online WWW]. Available URL: <http://soils.usda.gov/technical/classification/osd/index.html> [Accessed 10 February 2008]. USDA-NRCS, Lincoln, NE.

Nitrogen management for common bean crop in new and established no-tillage systems

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Abstract

The common bean crop has been increasingly cultivated in no-tillage systems, thus it is important to know the responses to nitrogen fertilization in soils under non-conventional management for different periods of time, considering that N availability is affected by the soil management system. This work aimed to evaluate the effects of sidedressed N fertilization rates (0, 30, 60, and 120 kg/ha) on common bean crop cultivated in newly implemented no-tillage system and established no-tillage system, without or with application of 60 kg/ha of N at bean sowing. In both systems (newly and established), N fertilization increased shoot dry matter production and grain yield of common bean; however, N applied at sowing was more efficient in increasing shoot dry matter. Even with the application of 60 kg/ha of N at sowing, common bean yield was increased by sidedressing N fertilization in both newly implemented and established no-tillage system. The efficiency of sidedressing N was greater in treatments receiving N at sowing.

Key Words

Phaseolus vulgaris, nitrogen, soil management system, no-tillage, grain yield.

Introduction

Brazil is the greatest common bean (*Phaseolus vulgaris* L.) producer in the world (Faoestat 2009). This legume crop is an important source of protein and energy for the nutrition of Brazilian people. Although the association with *Rhizobium* bacteria supplies the bean crop with part of the nitrogen (N), the amount supplied is not sufficient for the crop. Bean plants that are deficient in N show lower development and grain yield (Oliveira *et al.* 1996). Therefore, N supplied at the right time is fundamental for the bean plants to develop appropriately, because plants that are stronger, with more stems and that show more reproductive structures result in higher grain yield.

In tropical regions, no-tillage system is responsible to maintain soil sustainability. In the first years of no-tillage establishment, N immobilization in soil increases. At this time, organic matter works as a N sink, because soil organic matter accumulation exceeds decomposition, mainly if the soil is cropped with grasses. After some years of no-tillage establishment, soil conditions stabilize. As time goes by, residue decomposition increases N in soil, and this will be higher than the amount immobilized by microorganisms (Amado *et al.* 2002), so decreasing N demand. Nevertheless, appropriate management of N fertilization is one of the hardest to achieve.

The objective of this work was to evaluate the effects of N fertilization applied at sowing and/or side dressing on the bean crop cultivated in newly implemented and established no-tillage systems.

Methods

This work was carried out in 2007/08 and 2008/09, on Lageado Experimental Farm, Botucatu/SP - Brazil (48° 23' W and 22° 51' S, 765 m asl). The soil was a Red Nitosol (Alfisol), with 20.2%, 24.5%, and 52.3% of sand, silt, and clay contents, respectively. The experiment was arranged in a randomized complete block design with split-plots and four replications. Main plots consisted of four treatments: NNT - newly implemented no-tillage system (common bean crop was the first to be cropped in no-tillage system), ENT - established no-tillage system (23 years without soil tillage), NNT+N - NNT with application of 60 kg/ha of N at common bean sowing and ENT+N - ENT with application of 60 kg/ha of N at common bean sowing. Subplots consisted of four sidedressed N rates (0, 30, 60 and 120 kg/ha), applied at common bean V4 stage (third expanded trifoliate leaf) (Fernández *et al.* 1986), 20 days after seedling emergence (DAE). Nitrogen source was ammonium nitrate.

In fall-winter of 2007 and 2008 soil was cropped with yellow oat (*Avena byzantina* C. Koch). In December of 2007, chemical analysis of the soil in the experimental area was carried out, in the depths 0-10 and 10-20 cm (Table 1).

The area was treated about 15 days before bean sowing with the herbicide glyphosate (1.44 kg/ha of the active ingredient). Sowing of the Pérola cultivar was on 17 January 2008 and 06 January 2009, using 15 seeds per meter, in a 45 cm row spacing. At this time, P₂O₅ and K₂O were applied in all plots in the rates recommended for the crop. In previously specified plots, 60 kg/ha of N was also applied.

Shoot dry matter production at the time of flowering, N concentration in leaves and grain yield were evaluated. Data were subjected to an ANOVA (average across 2 years). System treatment means were compared by LSD test (P<0.05). Sidedressing N rates were analyzed through regression analysis, adopting the magnitude of regression coefficients that were significant at the 0.05 probability level by t-test as criterion for choosing the model.

Table 1. Soil chemical attributes at the depths 0-10 and 10-20cm. Average of four replications.

Prof. (cm)	Soil management	pH (CaCl ₂)	O.M. (g/dm ³)	P (resin) (mg/dm ³)	H+Al	K	Ca	Mg	CEC	Base saturation (%)
(mmol _c /dm ³)										
0-10	NNT	5.2	35.9	51.1	38.9	5.0	51.5	17.0	112.4	65
	ENT	5.3	40.2	81.5	38.3	5.7	61.6	22.6	128.2	70
10-20	NNT	5.2	32.6	36.9	39.6	3.2	61.9	19.4	124.1	68
	ENT	5.3	30.5	48.4	36.4	3.1	61.7	18.7	119.9	69

NNT - newly implemented no-tillage system, ENT - established no-tillage system, CEC - cation exchange capacity.

Results

Despite the different periods of time under no-tillage system, the soil of the experimental area showed good fertility level in both situations (Table 1).

For the treatments with 60 kg/ha of N at sowing (NNT+N and ENT+N), shoot dry matter production was higher than in the treatments with no N at sowing, even with the application of 120 kg/ha of sidedressing N (Figure 1A). Sidedressed N linearly increased dry matter, but only for the treatments with no N at sowing (NNT and ENT). However, for those treatments, with the sidedressing application of 120 kg/ha of N, dry matter production was lower than with the application of 60 kg/ha of N at sowing. There was no plant response to sidedressing N fertilization whenever N was applied at sowing. The results showed that N supplied at sowing resulted in better use of the fertilizer with effects on biomass production, considering that whenever N was applied at sowing there were higher values of plant dry matter. This emphasizes the importance of N fertilization in the initial stages of the bean crop. Although the maximum absorption of N is between flowering and grain filling (Hungria *et al.* 1985), the results showed that the bean crop requires N for its initial growth (Soratto *et al.* 2006), mainly when cultivated in no-tillage system after grasses.

Bean plants of the treatments with N applied at sowing (NNT+N and ENT+N) showed higher concentrations of this nutrient in leaves, whenever side dressing N was not applied (Figure 1B). Nitrogen applied at sowing increased N uptake by the plants, considering that it also increased shoot dry matter (Figure 1A) and N concentrations in the leaves (Figure 1B). Plants fertilized with 120 kg/ha of side dressing N in the treatment ENT+N showed higher concentrations of the nutrient in the leaves, which indicates higher N availability in soil for the established no-tillage system. Nevertheless, only for the treatments NNT and ENT with no side dressing N, bean plants showed N concentrations in the leaves that were below the optimum range (30-50 g/kg) considered appropriate for this crop (Ambrosano *et al.* 1996).

Irrespective of soil management, both sidedressing N and sowing application increased grain yield (Figure 1C). In the treatment NNT+N, sidedressed N increased bean yield up to the calculated dose of 84 kg/ha. In the other treatments, side dressing N fertilization linearly increased grain yield. However, the treatment ENT+N combined with the highest side dressing rate (120 kg/ha) resulted in higher grain yield (Table 2).

The greater availability of N in the initial stage of the crop, due to N application at sowing, increased the efficiency of sidedressed N, especially in the newly implemented no-tillage system (Table 2).

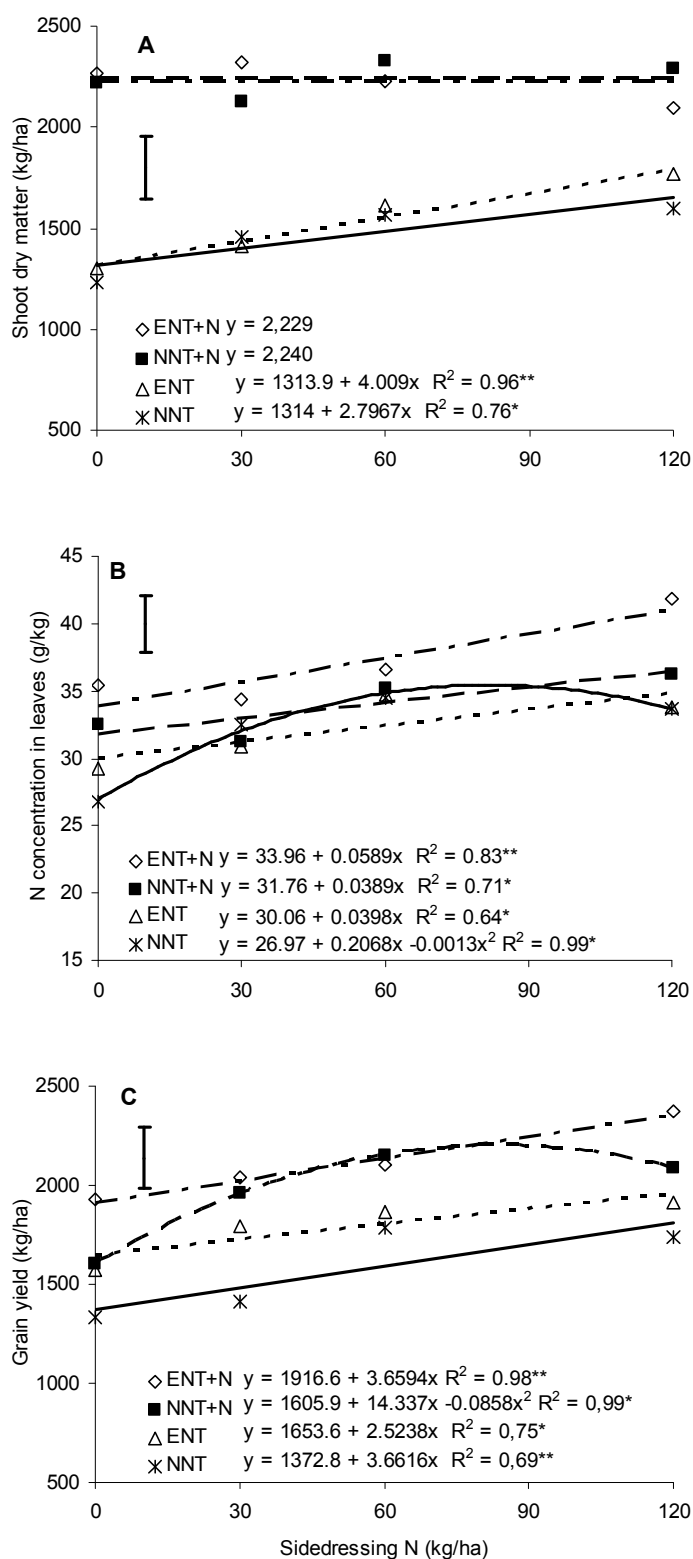


Figure 1. Shoot dry matter production (A), leaves N concentration (B) and grain yield (C) of common bean crop cultivated in newly implemented no-tillage system (NNT), established no-tillage system (ENT), newly implemented no-tillage system with N application at common bean sowing (NNT+N), and established no-tillage system with N application at common bean sowing (ENT+N) as affected by sidedressing N fertilization. * $P < 0.05$; ** $P < 0.01$. Vertical bars represent LSD values ($P < 0.05$).

Table 2. Common bean yields without sidedressed N, maximum yield, yield increase with N rate for maximum yield, amount of N for maximum yield and kilogram of common bean yield increased per kilogram of sidedressed N in newly implemented no-tillage system (NNT), established no-tillage system (ENT), newly implemented no-tillage system with N application at common bean sowing (NNT+N), and established no-tillage system with N application at common bean sowing (ENT+N).

Treatments	Yield without sidedressed N (kg/ha)	Maximum yield (kg/ha)	Yield increase with N rate for maximum yield (kg/ha)	N rate for maximum yield (kg/ha)	Sidedressed N use efficiency ¹ (kg/kg)
ENT+N	1926	2371	445	120	3.7
NNT+N	1604	2205	601	84	7.2
ENT	1574	1910	337	120	2.8
NNT	1332	1735	403	120	3.4

¹ Yield increase with N rate for maximum yield (kg/ha) per N rate for maximum yield (kg/ha)

Conclusion

In both newly implemented and established no-tillage systems, N fertilization increased shoot dry matter production and grain yield of common bean; however, N applied at sowing was more efficient in increasing shoot dry matter. Even with the application of 60 kg/ha of N at sowing, common bean yield was increased by sidedressing N fertilization in both newly implemented and established no-tillage system. The efficiency of sidedressing N was greater in treatments receiving N at sowing.

References

- Amado TJC, Mielniczuk J, Aita C (2002) Recomendação de adubação nitrogenada para o milho no RS e SC adaptada ao uso de culturas de cobertura do solo, sob sistema plantio direto. *Revista Brasileira de Ciência do Solo*, **26**, 241-248.
- Ambrosano EJ, Tanaka RT, Mascarenhas HAA, van Raij B, Quaggio JA, Cantarella H (1997) Leguminosas e oleaginosas. In 'Recomendações de adubação e calagem para o Estado de São Paulo'. (Eds B van Raij, H Cantarella, JA Quaggio, AMC Furlani) 2nd edn, pp.187-203. Boletim Técnico, 100. (Instituto Agrônomo e Fundação IAC: Campinas).
- Faostat (2009) Production, Crops, (Food and Agriculture Organization of the United Nations for a world without hunger: Rome) faostat.fao.org/site/567/default.aspx#ancor
- Fernandez F, Gepts P, Lopes M (1986) Etapas de desarrollo de la planta de frijol (*Phaseolus vulgaris* L.), (Centro Internacional de Agricultura Tropical: Cali)
- Hungria M, Neves MCP, Victoria RL (1985) Assimilação do nitrogênio pelo feijoeiro. II. Absorção e translocação do N mineral e do N₂ fixado. *Revista Brasileira de Ciência do Solo* **9**, 201-209.
- Oliveira IP, Araújo RS, Dutra LG (1996) Nutrição mineral e fixação biológica de nitrogênio. In 'Cultura do feijoeiro comum no Brasil'. (Coords. RS Araújo, CA Rava, LF Stone, MJO Zimmermann) pp.169-221. (Potafos: Piracicaba).
- Soratto RP, Carvalho MAC, Arf O (2006) Nitrogênio em cobertura no feijoeiro cultivado em plantio direto. *Revista Brasileira de Ciência do Solo* **30**, 259-265.

Nitrogen-15 uptake and distribution in two citrus species

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Abstract

Fruit yield of citrus is largely dependent on nitrogen fertilization, which it plays an important role in tree nutrition. An experiment was carried out in lysimeters (320 L), with 3-yr-old ‘Valencia’ sweet orange [*Citrus sinensis* (L.) Osbeck] and ‘Lisbon’ lemon (*C. limon* L.) trees grafted on ‘Swingle’ citrumelo [*C. paradisi* Macfad. x *Poncirus trifoliata* (L.) Raf.] and fertilized with ¹⁵N-enriched urea in different periods. The objectives of this study were (i) to evaluate the N partitioning for the biomass content of orange and lemon trees, (ii) to estimate the ¹⁵N uptake and recovery from labeled fertilizer applied to the soil in spring and summer periods, and (iii) to evaluate the nitrogen use efficiency by trees. The results showed that the dry mass accumulated in the lemon trees (6,499 g) was greater than in the orange trees (4,546 g). Total N concentration in the orange tree components was higher than in the lemon tree components. Total N fertilizer recovery was 36% for the orange trees and 52% for the lemon trees, for the average of the periods. The content of N derived from the fertilizer in the orange trees (74.6 g) was lower than for the lemon trees (98.6 g). Orange trees were less efficient in N use than the lemon trees.

Key Words

Orange, lemon, N fertilization, N absorption, N isotope, N use efficiency.

Introduction

The Brazilian citriculture has led world citrus production during recent years; the 20.8 million tonnes of fruit in 2007 represented about 19.1% of the overall world production (FAO 2009). Efficient nutrient management of citrus groves is critical to achieve high yields and crop quality. Nitrogen (N) is a key nutrient for production of citrus fruits, and the element plays an important role in vegetative and reproductive growth (Alva and Paramasivam 1998; Cantarella *et al.* 2003). The response of trees to N fertilization is likely to be influenced by endogenous N pools in the tree, N rates and application timing, sources of applied N, soil water availability, as well as soil N processes such as nitrification, denitrification, immobilization, leaching and volatilization (Martinez *et al.* 2002).

Soil analysis in Brazil has not been used for N recommendation for citrus, because it fails to correlate with fruit yield (Mattos Jr. *et al.* 1995). Leaf N analysis is a valuable tool for diagnosis of citrus tree nutrition and can also serve to predict N requirement (Quaggio *et al.* 1998). Adequate N content in the leaf for orange trees [*Citrus sinensis* (L.) Osb.] is around 27 g/kg (Quaggio *et al.* 1998), whereas for lemon trees [*C. limon* (L.) Burm. f.] a content higher than 18 g/kg does not indicate a positive effect of N fertilization on fruit yield (Quaggio *et al.* 2002). Adjustment of N fertilization recommendations for citrus, based on N dynamics in the tree is necessary to increase N uptake efficiency and minimize N losses in the soil-plant system (Syvertsen and Smith 1996). The aim of the work was (i) to evaluate the N partitioning in the biomass content of orange and lemon trees, (ii) to estimate the ¹⁵N uptake and recovery from labeled fertilizer applied to the soil in spring and summer periods, and (iii) to evaluate the nitrogen use efficiency by the trees.

Methods

The experiment was carried out with 3-yr-old trees of ‘Valencia’ sweet orange [*Citrus sinensis* (L.) Osbeck] and ‘Lisbon’ lemon (*C. limon* L.) both grafted on ‘Swingle’ citrumelo [*C. paradisi* Macfad. x *Poncirus trifoliata* (L.) Raf.]. The trees were the same size in the beginning of the study and were grown outdoors individually in lysimeters of 320 L filled with a clayey soil with, in g/kg, clay = 613 and sand = 161; nutrients were supplied according to Quaggio *et al.* (2005) and water was managed with aid of tensiometers and applied by drip irrigation.

The treatments were set up in a complete randomized factorial design of the type 2 x 2 (two species – orange and lemon; and two ^{15}N labelled applications – spring and summer) with three replicates. The annual N rate was 160 g/tree, which was split into two applications of 80 g/tree, in the spring and the same in the middle of the summer. The trees were ^{15}N fertilized with urea enriched in ^{15}N (2.1 atom% excess) just once either in the spring or in the summer. To avoid losses of N-NH_3 by volatilization, the urea was dissolved in water and applied to the soil surface; after the fertilization the lysimeters were irrigated to incorporate the fertilizer.

As soon as the fruits were mature, the trees were destructively harvested and separated into different components: new branches (<1.5 cm Ø) + leaves; old branches (1.5-4.0 cm Ø) + leaves; woody branches (>4.0 cm Ø); roots, mature fruits (last blooming) and new fruits (+/- 2.0 cm Ø). Tree components were weighed and sampled for determination of dry mass, N concentration and isotopic ratio.

Total N concentration and $^{15}\text{N}/^{14}\text{N}$ ratio were determined according to Barrie and Prosser (1996). The percentage of N in the plant components derived from the fertilizer (Ndff) and the total amount of N recovered (fertilizer N recovery) in different plant components were calculated using the isotopic dilution equation described by Hauck and Bremner (1976). The amount of ^{15}N recovered by citrus trees was calculated based on dry mass, total N and Ndff determination for the tree components.

Results

Dry mass, as well as total N concentration and N content of different tree components in both species are presented in Table 1. In the beginning of the experiment, orange and lemon trees had similar sizes; however, when the trees were destructively harvested, the dry mass of the lemon trees was 42% higher than that of orange trees. The largest proportion of total tree dry mass was found in the root, which represented 31% in the lemon and 40% in the orange trees. The lowest total N concentration was in the branches (woody, old and new) and the highest values were found in the leaves. N concentration in the orange tree components was higher than in the lemon trees. However, the total N content in the lemon trees was greater than in the orange ones, because of the total dry mass of the lemon trees was greater.

Table 1. Biomass distribution, total N concentration and N content in orange and lemon tree parts (values are means of 6 replicates $\pm$ standard deviation).

Plant part	Dry mass		N Concentration		N Content	
	Orange	Lemon	Orange	Lemon	Orange	Lemon
	g $\pm$ s(m) ^A		(g/kg) $\pm$ s(m)		g	
Young fruits	440 $\pm$ 115	1233 $\pm$ 379	14.6 $\pm$ 1.9	13.9 $\pm$ 1.9	6.5	17.2
Mature fruits	355 $\pm$ 136	181 $\pm$ 218	16.0 $\pm$ 0.8	12.8 $\pm$ 0.8	5.7	2.9
New leaves	630 $\pm$ 123	757 $\pm$ 103	28.2 $\pm$ 1.5	22.6 $\pm$ 1.5	17.7	17.1
Old leaves	105 $\pm$ 32	208 $\pm$ 82	27.1 $\pm$ 1.1	23.6 $\pm$ 1.1	2.8	4.8
New branches	325 $\pm$ 95	475 $\pm$ 118	10.9 $\pm$ 1.0	7.2 $\pm$ 1.0	3.6	3.4
Old branches	252 $\pm$ 51	507 $\pm$ 125	7.0 $\pm$ 0.5	5.0 $\pm$ 0.5	1.8	2.4
Woody branches	581 $\pm$ 160	1108 $\pm$ 227	5.4 $\pm$ 0.3	4.2 $\pm$ 0.3	3.1	4.5
Roots	1858 $\pm$ 424	2030 $\pm$ 260	17.7 $\pm$ 2.5	22.9 $\pm$ 2.5	33.4	46.3
TOTAL	4546 $\pm$ 371	6499 $\pm$ 445	(16.4) ^B	(15.2) ^B	74.6	98.6

^As(m) = the standard error of the mean, n = 6.

^BAverage in the whole tree

Nitrogen use efficiency is defined as the dry mass produced by unit nitrogen content of trees. Nitrogen concentration in the whole lemon tree (15.2 g/kg) was lower than in the whole orange tree (16.4 g/kg) (Table 1). It suggested that the lemon tree was more efficient in the use of N than the orange. Nitrogen uptake and fate of the labeled nutrient in the components of the citrus trees are shown in Table 2. The highest content of N uptake from fertilizer was found in the roots and new leaves. Tree N labeled period in the spring (220 days) was longer than the ^{15}N period in the summer (120 days); consequently, the content of ^{15}N in the trees that were fertilized in the spring was higher than those in the summer. The content of N derived from fertilizer in the lemon trees was higher than the orange trees, due to the higher ^{15}N recovered by the roots and the young fruits. Mattos Jr. *et al.* (2007) reviewed several experiment results in which the labeled ^{15}N was used; it was found that N recovered from urea by citrus trees in different production systems, ranged from 20 to 50%. In the present experiment, the total N recovery in the plant soil system was about 36% for orange trees and 52% for lemon trees at the end of the growth cycle (Table 2).

Table 2. Content of nitrogen derived from fertilizer (Ndff) in orange and lemon tree parts and N recovery of the labeled fertilizer in different fertilization periods (values are means of 3 replicates $\pm$ standard deviation).

	Spring		Summer	
	Orange	Lemon	Orange	Lemon
	g Ndff $\pm$ s(m) ^A			
Young fruits	3.53 $\pm$ 0.8	7.99 $\pm$ 1.9	1.62 $\pm$ 0.5	6.33 $\pm$ 1.7
Mature fruit	2.19 $\pm$ 1.3	2.08 $\pm$ 0.9	0.60 $\pm$ 0.1	0.18 $\pm$ 0.03
New leaves	8.22 $\pm$ 3.1	7.93 $\pm$ 2.0	5.58 $\pm$ 1.9	5.78 $\pm$ 1.6
Old leaves	1.10 $\pm$ 0.6	1.65 $\pm$ 0.5	0.63 $\pm$ 0.3	1.38 $\pm$ 0.5
New branches	1.57 $\pm$ 0.5	1.54 $\pm$ 0.3	1.36 $\pm$ 0.6	1.44 $\pm$ 0.5
Old branches	0.75 $\pm$ 0.1	1.12 $\pm$ 0.1	0.60 $\pm$ 0.2	0.68 $\pm$ 0.2
Woody branches	1.60 $\pm$ 0.6	1.84 $\pm$ 0.4	0.89 $\pm$ 0.3	1.49 $\pm$ 0.7
Roots	15.41 $\pm$ 4.1	18.91 $\pm$ 5.3	12.10 $\pm$ 4.8	22.91 $\pm$ 6.7
TOTAL	34.36	43.05	23.38	40.19
	%			
N recovery (relative to the total)	42.9	53.8	29.2	50.2

^As(m) = the standard error of the mean, n = 3.

Trees destructively harvested 220 days after spring application of ¹⁵N.

Trees destructively harvested 120 days after summer application of ¹⁵N.

Approximately 40% of the N in mature fruits was derived from the spring fertilization, even though only 10% was derived from the summer fertilization. On the contrary, the summer fertilization had a higher N contribution to the flowering in the next season (Table 3). Specific leaf weight is defined as leaf mass per unit area, and it is directly proportional to leaf thickness. By the results shown in the Figure 1A, the specific orange leaf weight was greater than the lemon leaf weight; this suggests that the lemon leaf is thinner than the orange leaf. In addition, the N concentration in the orange leaf was higher than in the lemon leaf, consequently, the specific orange leaf nitrogen, which is defined as leaf N content per unit leaf area (g m⁻² of N), was much higher than the specific lemon leaf nitrogen (Figure 1B).

Table 3. Nitrogen derived from the labeled fertilizer (Ndff) in flowers and fruits of orange and lemon trees in the different fertilization periods (values are means of 3 replicates $\pm$ standard deviation).

	Spring		Summer	
	Orange	Lemon	Orange	Lemon
	% Ndff $\pm$ s(m) ^A			
Mature fruit	37.6 $\pm$ 3.9	41.9 $\pm$ 6.9	10.3 $\pm$ 2.4	10.7 $\pm$ 0.4
Young fruits (2 cm Ø)	44.1 $\pm$ 5.5	42.4 $\pm$ 7.7	33.1 $\pm$ 5.8	36.2 $\pm$ 5.1
Flowers	37.9 $\pm$ 6.9	33.0 $\pm$ 6.4	40.9 $\pm$ 7.9	51.5 $\pm$ 2.6

^As(m) = the standard error of the mean, n = 3.

Fruit harvested 220 days after spring application of ¹⁵N.

Fruit harvested 120 days after summer application of ¹⁵N.

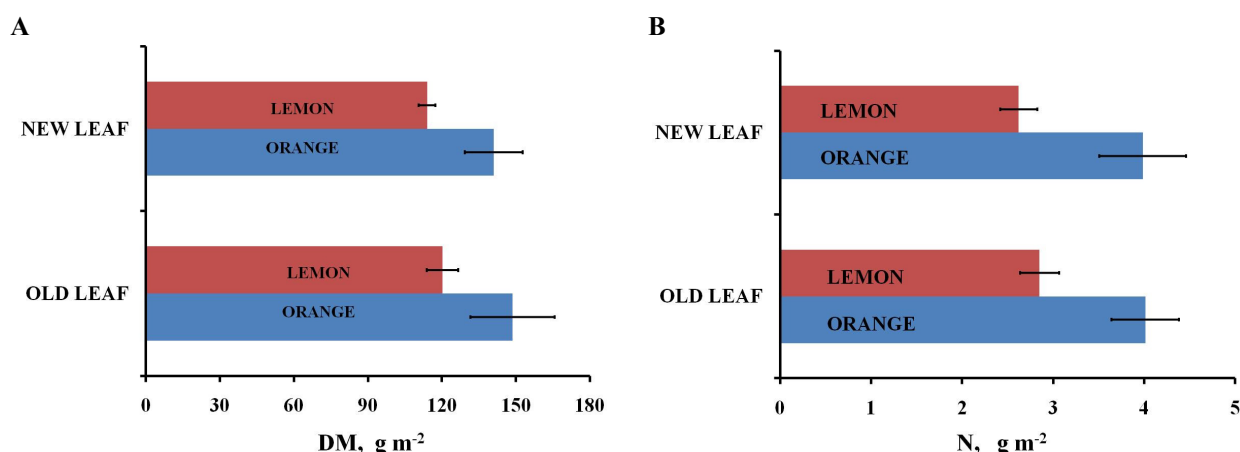


Figure 1. Specific leaf weight and specific leaf nitrogen (bars are the standard error of the mean, n=3).

Acknowledgements

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References

- Alva AK, Paramasivam S (1998) Nitrogen management for high yield and quality of citrus in sandy soils. *Soil Science Society American Journal* **62**, 1335-1342.
- Barrie A, Prosser SJ (1996) Automated analysis of light-element stable isotopes by isotope ratio mass spectrometry. In 'Mass spectrometry of soils'. (Eds TW Boutton, S Yamasaki) pp.1-46. (New York: Marcel Dekker)
- Cantarella H, Mattos JD, Raij B van (1994) Lime effect on nitrogen availability indexes as measured by plant uptake. *Communications in Soil Science and Plant Analysis* **25**, 989-1006.
- Hauck RD, Bremner JM (1976) Use of tracers for soil and fertilizer nitrogen research. *Advances Agronomy* **28**, 219-66.
- Martinez JM, Bañuls J, Quiñones A, Martín B, Primo-Milo E, Legaz F (2002) Fate and transformation of ¹⁵N labeled nitrogen applied in spring to *Citrus* trees. *Journal of Horticultural Science & Biotechnology* **77**, 361-367.
- Mattos JD, Quaggio JA, Cantarella H, Boaretto AE (2007) Nitrogênio e enxofre na cultura dos citros. In 'Nitrogênio e enxofre na agricultura brasileira'. (Eds T Yamada, SRA Stipp, GC Vitti) pp. 413-443. (Piracicaba: International Plant Nutrition Institute).
- FAO - Food and Agriculture Organization of United Nations (2009) www.faostat.fao.org
- Quaggio JA, Cantarella H, Raij B van (1998) Phosphorus and potassium soil test and nitrogen leaf analysis as a base for citrus fertilization. *Nutrient Cycling in Agroecosystems* **52**, 67-74.
- Quaggio JA, Mattos JD, Cantarella H, Almeida ELE, Cardoso SAB (2002) Lemon yield and fruit quality affected by NPK fertilization. *Scientia Horticulturae* **1836**, 1-12.
- Quaggio JA, Mattos JD, Cantarella H (2005) Manejo da fertilidade do solo na citricultura. In 'Citros' (Eds JD Mattos, JD De Negri, RM Pio, JJ Pompeu) pp.482-507. (Campinas: IAC e Fundag).
- Syvertsen JP, Smith JML (1996) Nitrogen uptake efficiency and leaching losses from lysimeter-grown *Citrus* trees fertilized at three nitrogen rates. *Journal American Society Horticulture Science* **121**, p.57-62.

Nutrient best management practice: the Australian experience

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Abstract

In the last decade, the challenges of the unique combination of soil, climate, ethnic background and economic drivers has moved Australian agriculture away from the original European practices to those more attuned to local conditions. Nutrient management has also been refined primarily to provide economic efficiency for low or no subsidy export oriented industries. More recently the impact of sub-optimal nutrient management methods on land that is adjacent to high visibility multi-use resources has changed nutrient best management from a productivity driven approach toward a balance between productivity, resource management and environmental protection. The challenge for the future is in maintaining an appropriate balance of food production and environmental conservation in the face of complex production issues and the integration of the changing demands of our modern society.

Key Words

Productivity, environment, economic, risk, social.

Introduction

Australia is a country of great physical diversity with unique combinations of predominantly geologically old soils, unreliable weather patterns and a wide diversity of plant species grown for food and fibre. With the diversified cultural backgrounds of the population, it is probably not unexpected that a somewhat unique approach to agricultural production would develop over time. Nutrient management, as part of agricultural production, has also developed some unique features. Agriculture in the 1900s began to move from a European style (frequent and intensive cultivation) toward what is probably now considered a unique and locally-adapted Australian approach to farming that is more attuned to the variability of the Australian climate and soils (Smith 2009). Some of these features are now being adopted in developing areas of the world with similar soils and climate. Management practices and products that reduce risk, on both input and output sides of production systems, have been adopted rapidly, e.g. the expansion in area of reduced and zero tillage, tram-lining, opportunity cropping and seed placement of starter P in broadacre grains; the green cane trash blankets in sugarcane, and the move to fertigation, drip and trickle irrigation in horticulture. The changes to soil and water management have had flow on effects to the fertiliser products, their application placement, timing and frequency. This is exemplified in the changes to cotton nutrient management that are integrated with improved water and insect management (Roth and Squires 2007, NLWRA 2008).

The development of new farming practices, together with changes in commodity prices and the introduction of new crops (e.g. canola in the mid 1980s) saw the rapid growth of nutrient use especially nitrogen (N) in this country (Figure 1). In Australia, there exists no single formal national framework or set of guidelines for developing nutrient best management practices (BMP). The programme that comes closest to a national nutrient BMP is FERTCARE®, a joint initiative of Australian Fertiliser Services Association (AFSA), the Fertilizer Industry Federation of Australia, (FIFA), and the federal Departments of Environment and Heritage (DEH) and Department of Agriculture, Fisheries and Forestry (DAFF), launched in 2004. This project was primarily developed to address emerging environmental issues associated with fertiliser use but quickly evolved a framework for nutrient BMP and adviser accreditation (FERTCARE® Accredited Adviser) for the fertiliser industry, (Drew 2007). It is yet to spread to the independent consultant network, although it has been recognized in recent State-based regulatory frameworks. Other nutrient BMPs that exist have generally been developed in response to industry segment productivity and to a lesser degree environmental issues, and/or as part of an extension add-on to a research project (Table 1). BMPs prior to mid 1990s generally focused on production optimisation, e.g. maximum economic return or production per unit of input only.

More recently research on the quality of water entering the Great Barrier Reef (GBR) and implications back to management of agricultural production (land) on the adjacent mainland, and the algal blooms in the Murray-Darling and Swan Rivers have been influential in changing the focus of nutrient BMP from a purely

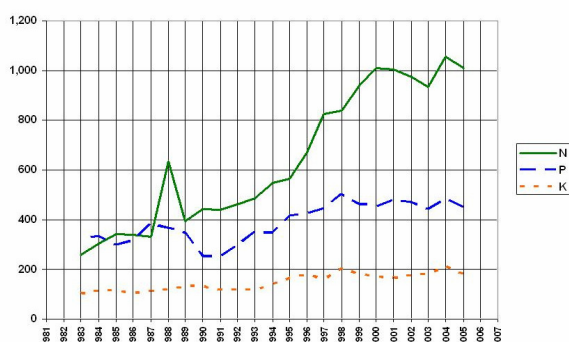


Figure 3. Nutrient consumption (kt of element) for Australia 1981-2007 (Source: Fertilizer Industry Federation of Australia).

production/ economic efficiency basis to having a growing consideration for resource and environmental conservation. More recently we have seen the quality of water entering the GBR and in the Swan coastal plain around Perth (WA), subject to a statutory regulatory approach to nutrient BMP to meet legislated targets in the management of environmentally active nutrients (N and P). In the case of the GBR, the sugar industry nutrient BMP (Six Easy Steps) has been a key component in formation of regulations that are able to accommodate both production and environmental objectives.

National Land and Water Resources Audit (2001) provided hard data to the growing undercurrent of opinion that vast tracts of agricultural land were being “mined” for nutrients, i.e. there was a net negative nutrient balance. This was further reinforced by results from the GRDC Nutrient Management Initiative (NMI) for the subtropical grain producing areas (Bell 2005).

Table 8. Recent major agricultural, pastoral and horticultural industry programmes containing nutrient BMP in Australia.

SEGMENT	PROGRAMME	ORGANISATION	DATE
Grains	GRDC Nutrient Management Initiative	DAFF	2005 - 2008
	Better Fertiliser Decisions – Grain	Grains Research and Development Corporation (GRDC)	2009 – 2012
Horticulture	Better Soils	Agricultural Bureau of South Australia	1997 - ongoing
	Northern Rivers Soil BMP Guide – Perennial Horticulture	NSW DPI, Landcare	2008 – ongoing
	Healthy Soil for Sustainable Farms – Ute Guide	AusVeg	2006 - 2008
Extensive Grazing	Making More from Sheep -	Meat and Livestock Australia (MLA), Australian Wool Innovations (AWI)	2004 – ongoing
	More Beef from Pastures	Meat and Livestock Australia	2004 – ongoing
	Better Fertiliser Decisions – Pasture	Victorian Department of Primary Industries (VDPI)	2003-07
Intensive Grazing	Better Soils	Agricultural Bureau of South Australia	1997 - ongoing
	Target 10 – Dairy	Dairy Australia, Victorian Department of Primary Industries	1998 – ongoing
	Better Fertiliser Decisions - Pasture	Victorian Department of Primary Industries (VDPI)	2003 - 07
Sugarcane	COMPASS	Bureau of Sugar Experiment Stations	2005 - ongoing
Cotton	Six Easy Steps		2005 - ongoing
	Australian Cotton Industry BMP Manual	Cotton Research and Development Corporation	2000 - ongoing
	Nutripak	Cotton Catchment Communities Co-operative Research Centre	2001 - ongoing
All	Healthy Soils for Sustainable Farming	DAFF	2006-2008
	FERTCARE ®	FIFA	2004 - ongoing

Nutrient BMPs need to be multi-dimensional to provide the necessary triggers for individuals to adopt any new practice. They must also provide the “working space” within their guidelines to allow for diversity and individuality that are important cornerstones of innovation, which is so important to the practical implementation of the scientific principles.

In times past, when management practices were generally driven to improve economic performance, extension was single dimensional, i.e. focus on parameters that were directly related to economic returns, i.e. nutrient use efficiency, \$ return/ kg input, net economic return/ha.

To be universally acceptable, new uniform nutrient BMPs must recognize that for most primary producers the dollar is now rarely the prime motivator for the adoption of new practices; rather it is a mix of financial security and risk, lifestyle tradeoffs, and how the change aligns with firmly held beliefs. Additionally this mix may vary according to the change in practice required (Figure 2). It is the influence of this curious mix of lifestyle, beliefs and risk preferences that has seen growth in practices and philosophies that challenge the balance between financial reward and protection or building soil properties and processes. In recent years the growth in organic agriculture, significant increase in consumption of “alternate” fertilizer products and the migration of mainstream farming toward more soil friendly practices, such as lower soil disturbance, retention crop residues and recycling of nutrient rich waste products are prime examples of this change.

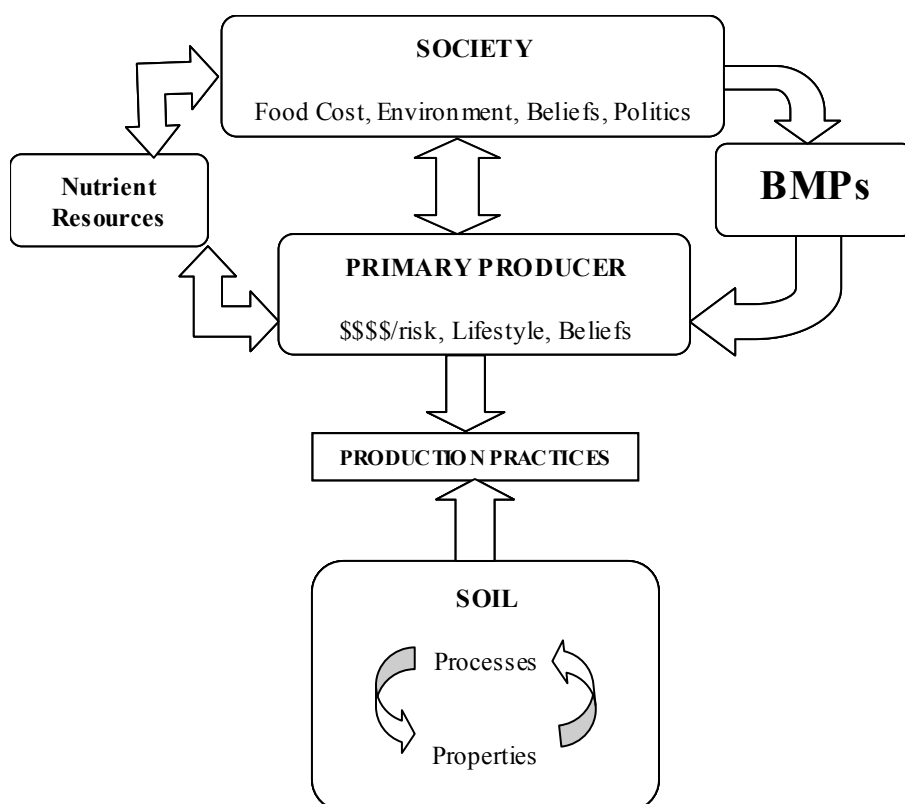


Figure 4. BMP framework partnership, the way forward.

Challenges for the Future

In Australia the changes and challenges in the production of food and fibre are likely to be in step with the rate of change in society in general. With declining rural political influence and the public expectation of cheap, clean, green, available and nutritious food, there exists a range of opportunities and challenges for the farm manager and his/her support network.

Food and fibre production needs to increase to keep pace with projected population growth, just as production efficiency needs to improve to maintain limited resources such as good quality soils, and water volume and quality. These must be achieved in the face of

- Reducing availability of suitable agricultural land
- Reducing water availability for food production
- Reducing public funding available for improving unit productivity
- Need to establish and maintain a socially acceptable production/ environment balance
- Maintaining a critical number of suitably trained agricultural and soil scientists to be able to provide intellectual horsepower to innovate and drive change.

References

- Bell M (2005) Chemical fertility and soil health in northern systems *Ground Cover* **56**, - Soil Biology Supplement.
- Drew N (2007) Fertcare ® - Putting Best Practice into Stewardship. IFA International Workshop on Fertilizer Best Management Practices, Brussels, Belgium, 7-9 March 2007. www.fertilizer.org/ifa/Home-Page/LIBRARY/Publication-database.html/Fertcare-R-Putting-Best-Practice-into-Stewardship.html, 5/10/2009.
- National Land and Water Resources Audit - Final Report (2001) Nutrient Balance in Regional Farming Systems and Soil Nutrient Status. www.anra.gov.au/topics/land/pubs/landuse/nutrient-balance.pdf
- National Land & Water Resources Audit (2008) 'Signposts for Australian Agriculture- The Australian Cotton Industry'. (NLWRA: Canberra).
- Roth G, Squires H (2007) How Far Has Soil Health Come in the Cotton Industry? In 'National Healthy Soils Symposium, Sunshine Coast, July 3-5 2007'.
- Smith DF (2009) Green myths about Australian farming. *The Australian Cottongrower* **30**, 43-45.

Nutrient best management practices for rice, maize, and wheat in Asia

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Abstract

Site-specific nutrient management (SSNM), as developed through more than a decade of research with rice (*Oryza sativa* L.) in Asia, now provides scientific principles on nutrient best management practices for rice, maize (*Zea mays* L.), and wheat (*Triticum aestivum* L.) in Asia. These scientific principles of SSNM enable the pre-season determination of crop needs for fertilizer nitrogen (N), the within-season distribution of fertilizer N to meet crop needs, and the pre-season determination of fertilizer phosphorus (P) and potassium (K) rates to match crop needs and sustain soil fertility. Fertilizer best management for each cereal crop is tailored to field-specific conditions for crop yield, crop residue management, historical fertilizer use, use of organic materials, and nutrient inputs through irrigation water. The widespread uptake by farmers of improved nutrient management requires transforming science-based information into locally adapted tools that enable extension workers, crop advisors, and farmers to rapidly develop and implement best management practices for specific fields and growing conditions. These tools that use information technology and other means for technology dissemination include decision support software, videos, quick guides for fertilizing rice, and the leaf color chart (LCC) for managing fertilizer N.

Key Words

Field-specific nutrient management, BMP, FBMP, fertilizer use efficiency, decision support software, Nutrient Manager.

Introduction

Rice, wheat, and maize are the major sources of calories for the rising human population in Asia. The production of these cereal staples must increase by 1.2% to 1.5% annually to meet rising demand and ensure food security. The closing of exploitable yield gaps through improved use of nutrient inputs is a key technology for helping achieve needed increases in cereal production. The development and widespread rapid uptake by cereal producers of best practices for managing fertilizers is consequently crucial for producing sufficient rice, wheat, and maize at affordable prices for consumers of these cereals and profitability for producers without damaging the environment.

Existing fertilizer recommendations for cereals often consist of predetermined rates of N, P, and K for vast areas. Such recommendations assume that the need of a cereal crop for nutrients is constant over time and over large areas. But, the growth and needs of a crop for supplemental nutrients can vary greatly among fields, seasons, and years as a result of differences in crop-growing conditions, crop and soil management, and climate. Hence, the management of nutrients for cereals requires an approach that enables adjustments in N, P, and K applications to accommodate the field-specific needs of the crop for supplemental nutrients.

More than a decade of research by the International Rice Research Institute (IRRI) and partners on the development, evaluation, and dissemination of site-specific nutrient management (SSNM) for rice across Asia fortunately provides scientific principles on field-specific management of nutrients for cereals. The concept of SSNM for rice emerged in the mid-1990s. It was evaluated and refined from 1997 to 2000 on about 200 irrigated rice farms in eight major rice-growing areas across Asia. From 2001 to 2004, the SSNM concept was systematically transformed to provide farmers and extension workers with locally adapted management of N, P, and K for rice. By 2004, the evaluation and promotion of locally adapted nutrient management practices based on the scientific principles of SSNM reached about 20 locations in Asia representing large areas of intensive rice farming. Improved yields and profitability as well as positive impacts on the environment were demonstrated across Asia (Pampolino *et al.* 2007), and the principles and merits of field-specific nutrient management for rice based on SSNM were widely distributed (Witt *et al.* 2007).

Since 2005, organizations across Asia have used SSNM principles arising from a decade of research on rice to develop and disseminate field-specific nutrient management practices for rice, wheat, and maize. Efforts have focused on harmonization among organizations within a country on nutrient best management

practices, building capacity of technical experts to facilitate the flow of information to local extension, and providing extension workers, crop advisors, and farmers with appropriate tools to quickly develop and implement best management practices for specific fields and growing conditions.

Principles of nutrient management

The SSNM approach provides the scientific principles for determining the amounts of N, P, and K that best match the field-specific needs of a cereal crop for supplemental nutrients. The approach originated from the direct relationship between crop yield and the need of the crop for a nutrient, as determined from the total amount of the nutrient in the crop at maturity (Witt *et al.* 1999). A targeted yield provides an estimate of the total nutrient needed by the crop. The portion of this requirement obtained from non-fertilizer sources is referred to as the indigenous nutrient supply.

The fertilizer N needed by a cereal crop to achieve a profitable target yield is determined from the anticipated yield gain to application of fertilizer N and a targeted efficiency of fertilizer N use to attain the targeted yield. The yield gain is the increase in grain yield due to fertilizer N, which is the difference between the target yield and yield without fertilizer N. Only a fraction of the fertilizer N applied to a cereal is taken up by the crop. Hence, the total amount of fertilizer N required for each tonne of increase in grain yield depends on the efficiency of fertilizer N use by the crop, which is defined as agronomic efficiency of fertilizer N (AEN) — the increase in yield per unit of fertilizer N applied.

The targeted AEN is adjusted for crop and crop response to N — based on results of field trials conducted across Asia in the development and verification of SSNM principles. The targeted AEN for rice typically ranges from a 16 to 25 kg increase in grain yield per kg applied fertilizer N (Witt *et al.* 2007). This corresponds to fertilizer N rates of 40 to 60 kg for a 1 tonne increase in grain yield. The targeted AEN tends to increase with increasing yield gain to N, and with hybrid maize it exceeds 30 kg grain/kg fertilizer N at high attainable responses to fertilizer N of 6 t/ha or more (Witt *et al.* 2009).

The SSNM approach provides guidelines for distributing fertilizer N among critical growth stages in order to match crop needs for supplemental N. With rice, only a small to moderate amount of fertilizer N is recommended within 14 days after transplanting or 21 days after direct sowing. The remaining fertilizer N is distributed to ensure sufficient N at early and mid-tillering to achieve an adequate number of panicles and at panicle initiation to increase grain number per panicle (Witt *et al.* 2007). For wheat, fertilizer N is distributed among pre-emergence, crown root initiation, and tillering stages (Alam *et al.* 2006). For maize, options are proved for application of fertilizer N either as three splits at V0 (0 to 7 days after planting), V6, and V10 stages or as two splits at V0 and V8 stages (Witt *et al.* 2009).

The leaf N content of a cereal crop is closely related to photosynthetic rate and biomass production, and it can serve as an indicator of N demand by the crop during the growing season. The leaf color chart (LCC) is an inexpensive and simple tool for monitoring the relative greenness of a rice leaf as an indicator of the leaf N status (Witt *et al.* 2005). A standardized plastic LCC with four panels ranging in color from yellowish green to dark green has been developed and promoted across Asia (IRRI 2010b). Although the LCC was originally developed for use with rice, it can be used for fine tuning the application of fertilizer N to wheat (Alam *et al.* 2006) and maize (Witt *et al.* 2009).

With the SSNM approach, fertilizer P and K are applied in sufficient amounts to overcome deficiencies and ensure profitable rice farming. Total P and K taken up by the crop are determined from the target yield and an established optimal reciprocal internal efficiency (kg nutrient in above-ground dry matter per tonne grain) for each crop (Witt *et al.* 1999). The total supply of P or K from sources other than fertilizer is estimated from the sum of the nutrient contained in retained crop residues, added organic materials, irrigation water, excess fertilization of the previous crop, and deposited sediment from floods. The difference between the total nutrient (P or K) taken up for the target yield and the nutrient supply provides a nutrient balance. A deficit in a nutrient balance reflects the amount of added nutrient required to avoid net removal of the nutrient from soil.

Fertilizer P and K requirements for a specific field are determined with SSNM using estimated target yield, nutrient balances, and expected yield gains from added nutrient. When yield gain to P or K is negligible, fertilizer P or K requirements are derived solely from the estimated nutrient balance. The nutrient rates can

match maintenance levels (i.e., nutrient input = output in the nutrient balance) when the soil is highly vulnerable to loss of sustained fertility due to nutrient mining. But such maintenance levels are unprofitable in the short term, and options are provided for supplying less than maintenance levels to increase profitability, especially when the soil contains a relatively large exploitable reserve of the nutrient and fertilizer prices are high relative to the cereal price. When yield gain to applied P or K is certain, fertilizer P or K requirements are determined from a combination of the nutrient balance and anticipated yield gain to nutrient application.

Dissemination of best management practices

The ultimate performance indicator of a successful nutrient management strategy is that many farmers quickly obtain and use science-based nutrient best management practices tailored to their specific field, crop, and season. The SSNM approach is a relatively knowledge-intensive technology in which optimum fertilizer management is tailored to field-specific conditions for crop yield, crop residue management, historical fertilizer use, use of organic materials, nutrient inputs in irrigation water, and, in the case of rice, the growth duration of the variety. This knowledge intensity of SSNM has slowed the wide-scale promotion and uptake by farmers of best management practices based on SSNM principles. Uptake by farmers can also be constrained by confusion arising from contrasting recommendations for nutrient management received from different organizations and technical experts.

The widespread uptake by farmers of improved nutrient management requires transforming science-based information into locally adapted tools that enable extension workers, crop advisors, and farmers to rapidly develop and implement best management practices for specific fields and growing conditions. Computer- and Internet-based decision support software capable within 15 minutes of providing farmers with nutrient management guidelines for specific fields with minimized risk and high likelihood of increased profit now form the backbone of locally adapted tools.

Consolidate knowledge into a verified decision tool

Through a partnership of public and private sector organizations in the Philippines, the results from more than a decade of research on SSNM for rice were used in 2008 to develop and verify decision support software targeted for extension and farmers in the Philippines. This decision software titled *Nutrient Manager for Rice: Philippines* was released on CD in 2008, and starting in 2009 it was available on the Internet in English and five dialects of the Philippines (IRRI 2010a). A partnership of organizations in Indonesia similarly developed decision support software tailored to rice production for Indonesia. It was released on CD in Bahasa Indonesia with the title *Pemupukan Padi Sawah Spesifik Lokasi (Location-Specific Rice Fertilization)* in 2008.

These decision tools are designed to help extension workers, crop advisors, and farmers quickly formulate fertilizer best management for specific rice fields. Each tool consists of 10–15 questions easily answered by an extension worker or farmer. Based on responses to the questions, a fertilizer guideline with amounts of fertilizer required by crop growth stage is provided for the rice field. Fertilizer rates and timing are adjusted to accommodate a farmer's use of organic sources of nutrients. These tools accommodate transplanted and direct-seeded rice, including inbred and hybrid varieties with a range of growth durations. These tools help farmers increase their yield and profit by applying the right amount of fertilizer at the right time.

The experiences of the Philippines and Indonesia with rice are now being replicated across Asia with rice, maize, and wheat. As of February 2010, decision tools for providing field-specific best nutrient management were under development and verification for wheat in India, maize in Bangladesh, and rice in Bangladesh, China, India, Sri Lanka, Vietnam, and West Africa (IRRI 2010b).

Provide a suite of locally adapted tools

Computer- and Internet-based decision tools are supplemented by a suite of additional locally adapted tools, including videos, quick guides for fertilization, and the LCC for managing fertilizer N. In the Philippines in 2009, *Nutrient Manager for Rice* decision support software was used to develop locally adapted fertilizer guidelines for the most common rice-growing conditions (i.e., crop establishment method, yield level, duration of rice varieties, and crop residue management) in 75 provinces. These guidelines were transformed in local dialects into provincial one-page quick guides for fertilizing rice that were distributed, demonstrated, and promoted in the provinces (IRRI 2010b). As of February 2010, this approach of developing and

disseminating quick guides for fertilizing rice was being replicated in Indonesia.

In 2009, a video titled *Proper Nutrition Makes Healthy Rice Plants* was released in the Philippines to provide farmers with guidelines on nutrient best management for rice (IRRI 2010b). The script was subsequently adapted to Indonesian conditions and a comparable video was released for farmers in Indonesia in the local language. As of February 2010, three additional videos were under development in the Philippines. Scripts from the videos will be circulated to encourage the development of locally adapted videos for farmers in other countries.

Conclusions

Experiences from the Philippines and Indonesia in transforming the scientific principles and research findings of SSNM into tools such as decision support software, videos, and quick guides for accelerating the uptake of nutrient best management serve as a model for replication with rice, maize, and wheat across Asia. Multi-institutional partnerships within the Cereal Systems Initiative for South Asia (CSISA) and the Irrigated Rice Research Consortium (IRRC) together with emerging public-private sector partnerships across Asia provide opportunities for accelerating the development, verification, dissemination, and uptake of locally adapted best nutrient management for cereals across Asia.

Acknowledgment

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References

- Alam MM, Ladha JK, Foyjunnessa, Rahman Z, Khan SR, Rashid H, Khan AH, Buresh RJ (2006) Nutrient management for increased productivity of rice–wheat cropping system in Bangladesh. *Field Crops Research* **96**, 374-386.
- IRRI (International Rice Research Institute) (2010a) Nutrient Manager for Rice. www.irri.org/nmrice. Accessed 24 February 2010.
- IRRI (International Rice Research Institute) (2010b) Site-specific nutrient management. www.irri.org/ssnm. Accessed 24 February 2010.
- Pampolino MF, Manguiat IJ, Ramanathan S, Gines HC, Tan PS, Chi TTN, Rajendran R, Buresh RJ (2007) Environmental impact and economic benefits of site-specific nutrient management (SSNM) in irrigated rice systems. *Agricultural Systems* **93**, 1-24.
- Witt C, Buresh RJ, Peng S, Balasubramanian V, Dobermann A (2007) Nutrient management. In 'Rice: A practical guide to nutrient management'. (Eds TH Fairhurst, C Witt, R Buresh, A Dobermann) pp. 1-45. (International Rice Research Institute, Los Baños, Philippines and International Plant Nutrition Institute and International Potash Institute: Singapore).
- Witt C, Dobermann A, Abdulrachman S, Gines HC, Wang G, Nagarajan R, Satawatananon S, Son TT, Tan PS, Tiem LV, Simbahan GC, Olk DC (1999) Internal nutrient efficiencies of irrigated lowland rice in tropical and subtropical Asia. *Field Crops Research* **63**, 113-138.
- Witt C, Pasuquin JMCA, Mutters R, Buresh RJ (2005) New leaf color chart for effective nitrogen management in rice. *Better Crops* **89**, 36-39.
- Witt C, Pasuquin JMCA, Pampolino MF, Buresh RJ, Dobermann A (2009) A manual for the development and participatory evaluation of site-specific nutrient management for maize in tropical, favorable environments. (International Plant Nutrition Institute: Penang, Malaysia) www.seap.ipni.net.

Nutrient best management practices need regional material flow management for soil protection

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Abstract

High-intensity animal farming regions are characterised by the production of animal manure nutrients in surplus of what can sustainably be used on the agricultural land. Theoretically, farms in those regions have a high potential for improving their overall productivity and environmental performance by implementing general nutrient and particular animal manure nutrient best management practices (BMPs). In reality, reducing animal manure application to a sensible degree leads to more costs for the export of surplus animal manure to other regions. If a nutrient BMPs framework is to be successful in regions with excess animal manure production, an optimization of animal manure distribution and transportation at lowest costs is a key element as it positively influences the farms' profitability. This case study from Germany provides a model for this purpose. A regional material flow management for animal manures based on this model will enable a substitution of mineral fertilizers with animal manures in regions with little animal farming. At the same time, environmental problems caused by manure over-application in the surplus regions can be reduced. Combining nutrient BMPs with models like this can help farmers in high-intensity animal farming regions and adjacent regions to increase productivity, profitability, system sustainability, and environmental protection.

Key Words

Phosphorus, nitrogen, linear optimization, land use, fertilizer ordinance, nitrates directive

Introduction

High-intensity animal farming regions are characterised by the production of animal manure nutrients in surplus of what can sustainably be used on the agricultural land. These regions often have a history of long-term over-application of manures with associated nutrient accumulation in the soils and nutrient loss to groundwater, surface waters and surrounding ecosystems. To prevent such adverse effects more or less extensive legal regulations regarding mineral fertilizer and animal manure application have been passed since the 1990s in most parts of the developed world. In Europe, national fertilizer ordinances implement the EC Nitrates Directive (1991) and regulate fertilizer use on the farm level. In some countries like The Netherlands, Belgium or Germany this leads to extensive and often costly animal manure exports from high-intensity animal farming regions to adjacent regions with lower animal densities (Wossink *et al.* 1992, Lauwers *et al.* 1998).

Theoretically, farms in high-intensity animal farming regions have a high potential for improving their overall productivity, system sustainability and environmental performance with the implementation of general nutrient and particular animal manure nutrient best management practices (BMPs). Most nutrient BMPs are more specific than general legal regulations as they aim at the right nutrient source at the right rate, right time, and right place. Through consideration of parameters such as the local soils, the crop nutrient demand and the animal manure nutrient composition, nutrient BMPs can facilitate specific applications of animal manures in combination with supplementary mineral fertilizers. At stable crop yields, the result is either a decrease of the total amount of animal manures applied or a partial substitution of mineral fertilizers or both.

In reality, the adaptation of animal manure nutrients BMPs in high-intensity animal farming regions is hampered by their own aims: Reducing the application of animal manure to a sensible and sustainable degree leads to more excess animal manure than legislation “generates” and hence to more export costs. This can decrease monetary farm success considerably. If an (animal manure) nutrient BMPs framework is to be successful in regions with excess animal manure nutrients production, a regional optimization of animal manure distribution and transportation at lowest costs is a key element as it directly and positively influences

the farms' profitability.

This case study from Germany highlights the need for a transport optimization scheme for animal manures to complete existing nutrient BMPs in high-intensity animal farming regions. It gives an example of a model which allows optimization of the distribution and transport of the animal manures in and between the administrative districts of north-west Germany at lowest costs. The model aims at avoiding manure over-application in the surplus districts and at the same time making use of the fertilizer value in districts with lower animal densities. Similar modelling approaches have so far considered the farm level instead of whole regions (Wossink *et al.* 1992) or "close" or "far" distances instead of actual distances (de Mol and Beek 1991). In all cases, the animal manure transport systems were modelled under the premise that the animal manure had to be disposed of instead of making use of the fertilizer value.

In this study, the most appropriate nutrient BMPs adapted to the actual land use, soils and surrounding ecosystems of specific smaller scale regions, farms, or fields are disregarded. The transport optimization module is being developed as an additional tool which can be used both on an aggregated regional level (for policy decision makers) as well as on the farm or field levels with site specific geographic information (for advisory services and extension).

Methods

Study area: Lower Saxony, north-west Germany

In Lower Saxony, a federal state in north-west Germany comprising 2.6 million hectares of agricultural land and 45 administrative districts, two major agricultural production zones can be distinguished. The north-western districts are dominated by dairy farming and high-intensity animal agriculture with high farm animal densities. Animal manure export to other districts is necessary but costly – especially for pig and cattle slurries that have high water contents. Long-term over-application of animal manures substantially increased overall and plant available soil phosphorus (P) contents (Leinweber 1996). The level of animal manure application decreased due to the first German Fertilizer Ordinance (DüV 1996). Yet, soil P accumulation slowly continues because legislation focuses on restricting nitrogen (N) application and N balance surpluses and because animal manures are usually applied based on crop N needs. As especially pig and poultry manures have high P contents, the amount of P applied to the soils usually exceeds the amount of P needed for crop growth. In the south-eastern and eastern districts intensive arable farming prevails. The majority of the crop nutrient demand is covered by mineral fertilizers. Long-term under-application of expensive mineral P fertilizers has resulted in large areas with low plant available soil P contents.

Input parameters for the model

The relevant parameters impacting on animal manure transports and their costs are quantity and quality of the manures produced and the capacity of land use systems to utilize manure as fertilizer.

The 29 animal manure classes considered in the model were determined by using district level data on number of farm animals sorted by species, use, age, and weight (LSKN 2004, TSK 2008). These were combined with the general reference values on N and P excretion of the farm animals and average amount of manure produced by the animals (LWK 2007). A simplifying assumption was made for the type of manure produced: all pig and all cattle manure was considered being slurry, all poultry manure was considered being solid manure.

The N and P demand of a total of 16 land use classes was derived by the combination of agro-statistics (LSKN 2008a) with average yield levels (LSKN 2008b) and fertilizing advice (LWK 2008).

Modelling

To optimize the distribution of manure nutrients at lowest transportation costs a linear optimization model was developed (Biberacher *et al.* 2009). Assumptions for the modelling are that each district can provide nutrients in animal manures and that each district comprises areas of various land uses with a specific nutrient demand. The extent to which the manures are transported depends on local manure production, scenario constraints on manure nutrient application and manure availability after transportation between districts as depending on the constraints. The modelling language is GAMS (General Algebraic Modelling System). The model is linked to an Excel template for data input and result visualization. Its output is the optimal animal manure distribution to the agricultural land and the minimal animal manure transport

between all districts at lowest overall transportation effort. An additional output is the definition of animal manure nutrient deficient or surplus districts as depending on the constraints.

Two scenarios are used for this study. Scenario 1 serves a baseline scenario with compliance to the minimum legal regulations for animal manures. According to the German Fertilizer Ordinance (§5 DüV 2007), a maximum of 170 kg N/ha/a from animal manures may be applied to the farm land. Scenario 2 simulates the adaptation of nutrient BMPs that aim at no further increase of the high plant available soil P levels in the high-intensity animal farming districts. Covering 100% of the crop nutrient demand by organic manure nutrients is not a sensible option from many viewpoints, e.g. regarding plant nutritional and nutrient leaching aspects. In scenario 2, animal manure P and N may be applied up to 80% of the crop demand.

Results and Discussion

Restricting animal manure application to a maximum of 170 kg N/ha/a (scenario 1, Figure 1a) results in far less extensive manure transportation activities between the districts of Lower Saxony than the constraints of scenario 2 that restrict animal manure application to a maximum of 80% of the crop nutrient demand (Figure 1b, 1c). In the model, most western districts with comparatively high animal densities become manure surplus districts and have to export manure in scenario 2. A total of 3 million tons of manure is exported from 19 surplus districts. Nevertheless, most of the manure is used locally in the districts of origin. The liquid slurries are mainly used locally to cover the local crop nutrient demand or, if districts are surplus districts, are exported into districts close by. A detailed view into the manure exports from Cloppenburg (CLP) district shows how the model gives preference to the transportation of water rich slurries to the close vicinity only (Figure 1b, 1c). In contrast to the slurries, poultry dung is transported to the more distant districts because of its low water and high nutrient content.

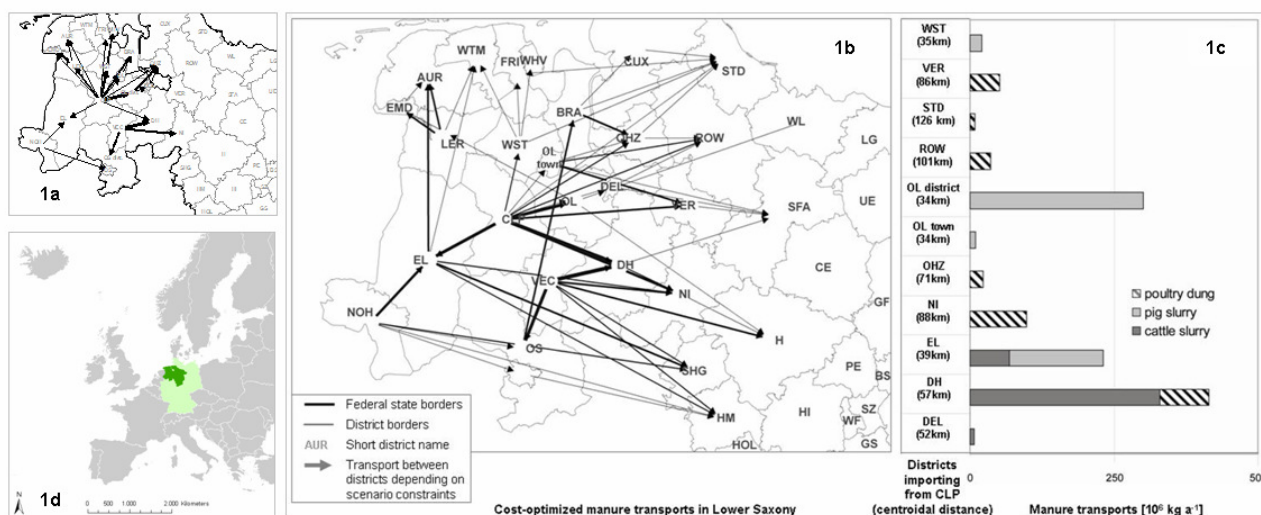


Figure 1. Modelling results: Manure transport and distribution in scenario 1 (Figure 1a) under compliance with §5 DüV (2007) (max. 170 kg N/ha/a) and in scenario 2 (Figure 1b and 1c) if animal manure P and N may cover a maximum of 80% of the crop demand. Figure 1a and 1b depict the least possible transport effort of manures between the districts in Lower Saxony at model constraints. Bold/slim arrows indicate large/small manure flows. Figure 1c gives an example of how the model distributes the different types of manure from a surplus district (Cloppenburg, CLP) to the receiving districts in scenario 2. The cumulative terms of poultry dung, pig slurry and cattle slurry contain the 29 manure classes of the model. Figure 1d shows the location of Lower Saxony in Germany and Europe.

Even at transport optimization as simulated by the model, costs associated with the export of excess animal manure are high. In reality, these costs were even higher due to the lack of the universal knowledge of supply and demand that the model has. These figures show that an actual adaptation of nutrient BMPs that indirectly increase animal manure surpluses in the high-intensity animal farming regions can only be expected if the farmers will be able to give away excess animal manure for little money or for free or if they can even make profits. Hence, a basic model setup as presented in this study can considerably contribute to reaching the overall aims of nutrient BMPs: to help farmers in high-intensity animal farming regions and the adjacent regions to increase productivity, profitability, system sustainability, and environmental protection. However, modifications in the model setup are required before that. The current setup of the model is regional, based on aggregated data, and aims at policy makers. Advisers for farmers or animal manure transport agencies

need different setups which include site-specific geographic information. The model can be easily adjusted for such purposes.

Conclusion

A framework for nutrient BMPs in high-intensity animal farming regions must comprise a solution for transport optimization of animal manures to become accepted. A regional material flow management for animal manures based on models like this will enable a reasonable substitution of often expensive, limited and energy-intensive mineral fertilizers with animal manures in regions with little animal farming. At the same time, environmental problems caused by manure over-application can be reduced in high-intensity animal farming regions.

References

- Biberacher M, Warnecke S, Brauckmann H-J, Broll G (2009) A linear optimisation model for animal farm manure transports in regions with high intensity animal farming. In '18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation, July 2009' (Eds RS Anderssen, RD Braddock and LTH Newham) pp. 470-476. ISBN: 978-0-9758400-7-8. http://www.mssanz.org.au/modsim09/B1/biberacher_B1.pdf
- DüV, Düngeverordnung (1996) Verordnung über die Grundsätze der guten fachlichen Praxis beim Düngen. Düngeverordnung in der Fassung der Bekanntmachung vom 26. Januar 1996 (BGBl. I 1996 S. 118).
- DüV, Düngeverordnung (2007) Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis. Ausfertigungsdatum 10. Januar 2006 (BGBl. I S. 33). Düngeverordnung in der Fassung der Bekanntmachung vom 27. Februar 2007 (BGBl. I S. 221).
- EC Nitrates Directive (1991) Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, Official Journal L 375, 31/12/1991 pp. 0001 – 0008.
- GAMS, General algebraic modeling system, GAMS Development Corporation, <http://www.gams.com/>, 04.03.2009.
- Lauwers L, Van Huylenbroeck G, Martens L (1998) A Systems Approach to Analyse the Effects of Flemish Manure Policy on Structural Changes and Cost Abatement in Pig Farming, *Agricultural Systems*, Vol. 56, No. 2, 167-183.
- Leinweber P (1996) Phosphorus fractions in soils from an area with high density of livestock population. *Z. Pflanzenernaehr. Bodenk.* 159, 251-256.
- LSKN, Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen (2004) Agrarstrukturerhebung 2003. Viehhaltung.
- LSKN, Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen (2008a) Agrarstrukturerhebung 2007. Bodennutzung.
- LSKN, Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen (2008b) Erntestatistik der Jahre 2003 bis 2008.
- LWK, Landwirtschaftskammer Niedersachsen (2007) Nährstoffausscheidungen landwirtschaftlicher Nutztiere je Stallplatz und Jahr. Ausfertigungsdatum 25.04.2007.
- LWK, Landwirtschaftskammer Niedersachsen (2008) Richtwerte für die Düngung in Niedersachsen. Stand März 2008. http://www.lwk-niedersachsen.de/download.cfm?file=341_duengeempfehlung2008~pdf, 17.12.2008.
- Mol M de, Beek P (1991) An OR contribution to the solution of the environmental problems in the Netherlands caused by manure. *European Journal of Operational Research*, 52, 16-27.
- TSK, Niedersächsische Tierseuchenkasse (2008) Unpublished data on number of animals in the districts of Lower Saxony on 02.01.2008.
- Wossink GAA, de Koeijer TJ, Renkema JA (1992) Environmental-Economic Policy Assessment: A Farm Economic Approach. *Agricultural Systems*, 39, 421-438.

Nutrient best management practices: Western perspectives on global nutrient stewardship

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Abstract

A global framework designed to aid the development and adoption of fertilizer best management practices (FBMPs) is described within the context of sustainable development. The framework is based on the premise that four principles of nutrient management—right source, right rate, right time, and right place—provide the basis and flexibility needed for nutrient management in global agriculture and be adaptable from small to large farmers.

Key Words

4Rs, nutrient best management practices, BMPs.

Introduction

Agriculturalists have been implementing and refining nutrient management since farmers first recognized crop growth could be enriched by the use of animal manures, composts, ashes, fish meal, bones, and other soil additives. However, the idea of nutrient best management practices (BMPs) is a relatively recent concept. Defined by fertilizer industry scientists as research proven practices that have been tested through farmer implementation to optimize production potential, input efficiency, and environmental protection (Griffith and Murphy 1991), BMPs related to nutrients encompass a host of terms. Fertilizer best management practices, integrated plant nutrient management, code of best agricultural practices, site-specific nutrient management, and other similar expressions are all descriptive components of plant nutrient management. All have an underlying goal to help ensure plant nutrients are used efficiently and effectively in ways that are beneficial to society without adversely impacting our environment. The concepts involved can best be described through global guidelines for nutrient stewardship. Three years ago the International Fertilizer Industry Association (IFA) launched an initiative on FBMPs with an international workshop in Brussels to define general principles of FBMPs and to develop a strategy for their wider adoption. During that workshop, Fixen (2007) introduced the idea of a global framework within which FBMPs could be adapted to local conditions. Since then, the concept of a global framework for FBMPs has been further developed by IPNI scientists (Bruulsema *et al.* 2008) and an IFA Task Force on FBMPs culminating with the publication of *The Global “4R” Nutrient Stewardship Framework* (IFA Task Force 2009). The framework is intended to aid the development and adoption of nutrient BMPs that meet sustainable development goals (i.e. economic, social, and environment) through simultaneously increasing crop productivity and profitability, while protecting the environment.

Sustainability

The global framework recognizes there are many stakeholders interested in nutrient management—farmers, crop advisers, scientists, policymakers, consumers, and the general public. Each stakeholder has different expectations of nutrient management which revolve around the pillars of sustainability. Farmers need to be profitable and, as stewards of the land, desire to protect their natural resource; the public wants safe, nutritious food, a clean environment, and land for forests, wildlife, and recreation, and policymakers want to ensure we produce enough food while providing for the needs of current and future generations. These are all components of sustainability supported by economic, social, and environmental goals. Ideally, these three pillars of sustainability would be equally balanced, but in reality that does not occur. The balance between economic, social, and environmental goals for nutrient management depends on the issue, its context, and the stakeholders (IFA Task Force 2009). In some sensitive ecosystems, more emphasis might be placed on environmental goals, where in other situations social goals may be of greatest concern or economics (i.e. farmer profitability) may dominate. Regardless of the balance, it is constantly changing with improvements in knowledge and technology and changes in stakeholder expectations.

4R nutrient stewardship

The global 4R nutrient stewardship framework attempts to integrate the economic, social, and environmental expectations of the different stakeholders within cropping system management objectives of productivity, profitability, cropping system durability, and a healthy environment (Figure 1). Central to the framework are the 4Rs—right nutrient source (or product), applied at the right rate, time, and place.

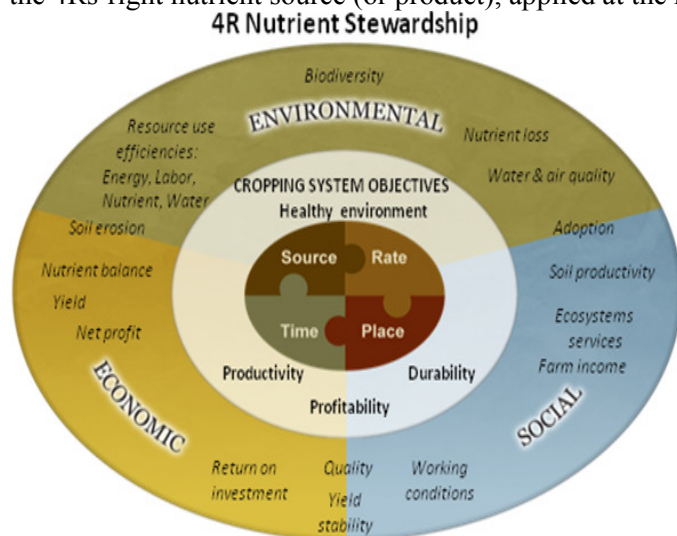


Figure 1. The 4R nutrient stewardship concept defines the right source, rate, time, and place for plant nutrient application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the soil-plant ecosystem.

The 4Rs are the foundation and guiding principles of nutrient BMPs (Roberts 2007). The approach is simple and universally applicable ... apply the correct nutrient in the amount needed, timed and placed to meet crop demand. Examples of the 4 rights of nutrient stewardship include:

Right Source – match the nutrient source or fertilizer product with soil properties and crop needs. Apply nutrients in plant-available forms. Balance applications of nitrogen, phosphorus, potassium, and other nutrients according to crop needs and available soil nutrients. Beware of nutrient interactions, blend compatibility, and non-nutritive elements.

Right Rate – Match application rates with crop requirements. Set realistic yield goals and use adequate methods to assess soil nutrient supply (e.g. soil testing, omission plots) and crop need (e.g. tissue analysis, crop nutrient budgets, crop scouting). Predict fertilizer use efficiency, consider economics and soil resource impact.

Right Time – Assess timing of crop uptake and synchronize nutrient availability with crop demand. Assess soil nutrient supply. Utilize pre-plant, split applications, controlled release fertilizers, and urease and nitrification inhibitors to manipulate the timing of nutrient availability and consider logistics of field operations.

Right Place – Recognize root-soil dynamics. Place and keep nutrients where the crop needs them and where nutrient use efficiency will be maximized. Crop, cropping systems, and soil properties will dictate the most appropriate method of placement, but incorporation is usually preferred to keep nutrients in place and increase their use efficiency. Beware of and manage spatial variability.

Right source, rate, time, and place are science-based principles of fertilizer management. Each of the 4Rs is guided by scientific principles and supported by years of research. They are not static, but are changing and improving with new gains in knowledge and technology development. They are interdependent and interlinked with agronomic management practices applied in cropping systems (Bruulsema *et al.* 2009). The 4Rs provide flexibility to nutrient management recognizing that FBMPs are site and crop specific depending on soils, climatic conditions, crop and cropping history, and management expertise, and can be applied in large-scale, extensive agriculture or small family farms. In-depth discussions of nutrient source, rate, time, and place have recently been published by the American Society of Agronomy as a five-part series titled “Know Your Fertilizer Rights” (Mikkelsen *et al.* 2009; Phillips *et al.* 2009; Stewart *et al.* 2009; Murrell *et al.* 2009).

The framework shows the interaction between BMPs and allows assessment of FBMPs on the cropping system performance within the goals of sustainability. Performance is the outcome of implementing a FBMP. Figure 1 shows various cropping performance indicators, i.e. yield, quality, soil productivity, nutrient loss, etc. and how they are interconnected. A “best” management practice should positively address at least two and preferably three goals of sustainability within the cropping systems. For example, nutrient use efficiency is often considered the foremost performance indicator relative to fertilizer use. Nutrient use efficiency can be increased simply by reducing application rates (Roberts 2007). If the objective of nutrient management was to maximize nutrient use efficiency, then the farmer would merely target lower parts of the yield response curve where the first increments of applied fertilizer gives the greatest yield response. Singling out rate reductions could reduce nutrient loss (beneficial for the environment), but it may also negatively impact yields and profitability, reducing the economic sustainability of the farmer. Performance measures or indicators must be considered within a cropping system and in relation to the goals of sustainability. They are set by the farmer, his or her advisers, and other stakeholders in society concerned with how nutrients are managed. The need for and usefulness of performance indicators in improving FBMPs is outlined at greater length by Bruulsema *et al.* (2009) and by the IFA Task Force (2009).

Concluding comments

Right source, right rate, right time, and right place is a simple slogan that integrates a century of science and experience into nutrient stewardship. Who decides what is right? Who decides the best application, best method of placement, or best nutrient source? There is no right answer ... right must be site-specific, dictated not only by soil and environmental conditions, but by social and environmental concerns and objectives. Research backstops the principles of 4Rs with science, but the stakeholders decide what is right. The farmer, the fertilizer industry, natural resource managers, extension workers, crop advisers, environmental NGOs, and others with a vested interest help in deciding what is the right or best nutrient management practice. The people impacted by nutrient management decisions, i.e. the consumer, are also involved and policymakers help make those decisions for them.

Nutrient use regulatory and policy developments are becoming common place in North America and the European Union. 4R nutrient stewardship provides a voluntary option to address nutrient related regulatory issues, whether they are related to water quality or greenhouse gases (GHG). In North America, IPNI has been working with The Fertilizer Institute (TFI) and the Canadian Fertilizer Institute (CFI) to promote the adoption of the 4R system within legislative and regulatory frameworks. Currently in the U.S., 4R nutrient stewardship has been endorsed by the United States Department of Agriculture (USDA), through both the Natural Resources Conservation Service (NRCS) draft 590 standard and through consideration of a Memorandum of Understanding of the USDA Climate office. The 4R system has also been sanctioned by state fertilizer associations, the Association of American Plant Food Control Officials (AAPFCO), the Conservation Technology Information Center (CTIC), and the American Farm Bureau Federation (AFBF) as well as other agricultural organizations. In Canada, the Province of Alberta has recognized 4Rs are part of its nitrous oxide emissions reduction protocol (NERP) and other provinces are looking to 4Rs as a voluntary means to assist farmers in reducing GHG emissions. Carbon credit and offset trading programs are considering 4R nutrient stewardship as an acceptable method of recognizing farmers’ contributions to earning credits.

Farmers can achieve better management through implementation of 4R nutrient stewardship. Validated by research, the 4R nutrient stewardship framework allows farmers to improve their performance and sustainability. Economic, social, and environmental performance is reflected through performance indicators chosen by the stakeholders of the cropping system. 4R nutrient stewardship is gaining global acceptance, but continued education and multi-stakeholder dialog between farmers, the fertilizer industry, policymakers, and other relevant groups are still needed to keep moving forward.

References

- Bruulsema TW, Witt C, Garcia F, Li S, Rao TN, Chen F, Ivanova S (2008) A global framework for fertilizer BMPs. *Better Crops with Plant Food* **92**, 13-15.
- Bruulsema TW, Lemunyon J, Hertz B (2009) ‘Know your fertilizer rights’. *Crops & Soils*/March-April 2009. (American Society of Agronomy, Madison, WI).
- Griffith WK, Murphy LS (1991) ‘The development of crop production systems using best management

- practices'. (Potash & Phosphate Institute: Norcross, USA).
- Fixen PE (2007) Can we define a global framework within which fertilizer best management practices can be adapted to local conditions? In Fertilizer Best Management Practices. In 'IFA International Workshop on Fertilizer Best Management Practices (FBMPs). 7-9 March 2007, Brussels, Belgium'.
- IFA Task Force (2009) The global "4R" nutrient stewardship framework. Developing fertilizer best management practices for delivering economic, social, and environmental benefits. In 'IFA Task Force on Fertilizer Best Management Practices. International Fertilizer Industry Association (IFA). Paris, France'. AgCom/09/44. A/09/116
- Mikkelsen R, Schwab G, Randall G (2009) 'The four rights: selecting the right source'. Crops & Soils/ May-June 2009. (American Society of Agronomy. Madison, WI).
- Murrell TS, Lafond GP, Vyn TJ (2009) 'Know your fertilizer rights: right place'. Crops & Soils. March-April 2009. (American Society of Agronomy. Madison, WI).
- Philips SB, Camberato JJ, Leikam D (2009) 'Selecting the right fertilizer rate: a component of 4R nutrient stewardship'. Crops & Soils/July-August 2009. (American Society of Agronomy. Madison, WI).
- Roberts TL (2007) Right product, right rate, right time and right place the foundation of best management practices for fertilizer. In 'Fertilizer Best Management Practices. IFA International Workshop on Fertilizer Best Management Practices (FBMPs). 7-9 March 2007, Brussels, Belgium'.
- Stewart WM, Sawyer JE, Alley MM (2009) 'The four rights: timing'. Crops & Soils/September-October 2009. (American Society of Agronomy. Madison, WI).

Optimal nitrogen fertilization timing for upland rice

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Abstract

Nitrogen is one of the most yield limiting nutrients for upland rice production in South America, including Brazil. A greenhouse experiment was conducted to determine optimal nitrogen fertilization timing for upland rice grain yield and yield components. The total N applied was 300 mg/kg and N timing treatments were: T₁ (1/2 N applied at sowing + 1/2 applied at panicle initiation), T₂ (total N applied at sowing), T₃ (1/3 N applied at sowing + 1/3 N applied at active tillering + 1/3 N applied at the panicle initiation), T₄ (1/2 N applied at initiation of tillering + 1/2 N applied panicle initiation), and T₅ (2/3 N applied at sowing + 1/3 N applied at panicle initiation). Grain yield, shoot dry weight, panicle number, and grain harvest index were significantly influenced by N timing treatments. Maximum grain yield was obtained with one-third N applied at sowing + one-third applied at active tillering and remaining one-third applied at panicle initiation. Total N applied at sowing produced minimum grain yield, shoot dry weight, and panicle number. Shoot dry weight and panicle number were positively and significantly related to grain yield.

Key Words

Grain yield, grain harvest index, *Oryza sativa* L., yield components

Introduction

Rice is a staple food crop for more than 50% of the world population (Fageria *et al.* 2003). Upland rice is defined as the rice grown on undulated or flat well drained soils, without water accumulation in the field during crop growth cycle and totally depends on rainfall for water requirements. Upland rice is also known as aerobic rice is mainly grown in South America, Africa and Asia (Fageria 2002). In South America, upland rice is an important crop in cropping systems. It is mainly grown in rotation with soybean or dry bean. In cerrado region of Brazil (central part of the country), upland rice is first grown after clearing the land for pasture establishment. Nitrogen is one of the most yield limiting nutrients for annual crops around the world and its efficient use is important for economic sustainability of cropping systems. Furthermore, the dynamic nature of N and its propensity for loss from soil-plant systems creates a unique and challenging environment for its efficient management (Fageria and Baligar 2005). Recovery of N in crop plants is usually less than 50% worldwide (Raun and Johnson 1999). This has led to environmental contamination and concerns regarding use of N fertilizers. The low recovery of N is associated with its loss by leaching, volatilization, denitrification and erosion of the soil. Nitrogen rate and timing are important crop management practices for improving N use efficiency and crop yields (Fageria and Baligar 2005). In addition, improving N use efficiency can reduce cost of crop production as well as environmental pollution. Synchrony of N supply with crop demand is essential in order to ensure adequate quantity of uptake and utilization and optimum yield. No suitable soil test method has been established and implemented for determining the N supplying capacity for soils used to produce rice (Dobermann and Fairhurst 2000). Synchrony of nutrient supply with crop demand can improve crop yield and quality and avoiding negative environmental impacts. The objective of this study was to determine optimal timing of N fertilization on grain yield and yield components of upland rice.

Materials and methods

A greenhouse experiment was conducted at the National Rice and Bean Research Center of Embrapa, Santo Antônio de Goiás, Goiás, Brazil to determining optimal N fertilization timing for upland rice. The soil used in the experiment was an Oxisol and was having chemical and physical properties as pH 5.7, Ca 1.26 cmol_c/kg, Mg 0.64 cmol_c/kg, Al 0.1 cmol_c/kg, P 1.7 mg/kg, K 39 mg/kg, Cu 1.3 mg/kg, Zn 1.1 mg/kg, Fe 65 mg/kg, Mn 14 mg/kg, and organic matter 23 g/kg. The textural values were clay 643 g/kg, silt 100 g/kg, and sand 257 g/kg. The experiment was conducted in plastic pots with 9 kg of soil in each pot. The total N applied was 300 mg/kg and N timing treatments were: T₁ (1/2 N applied at sowing + 1/2 applied at panicle initiation), T₂ (total N applied at sowing), T₃ (1/3 N applied at sowing + 1/3 N applied at active tillering + 1/3 N applied at the panicle initiation), T₄ (1/2 N applied at initiation of tillering + 1/2 N applied panicle initiation), and T₅ (2/3 N applied at sowing + 1/3 N applied at panicle initiation). Each pot received 200 mg P

and K and 5 mg Zn/kg of soil at sowing time. The N was applied as urea, P as super triple, K as potassium chloride and Zn as zinc sulfate. In addition, 10 g dolomitic lime was added four weeks before sowing and pots were subjected to wetting and drying cycles. An advance line of upland rice BRA052023 was planted. After germination four plants were maintained in each pot. completely randomized block design was used with four replications. Pots were irrigated daily to maintain soil moisture at about field capacity. Plants were harvested at physiological maturity. At the time of harvesting, panicles and shoots were harvested separately and dried to a constant weight at 70 °C. Grain harvest index was calculated by using the following formula (Fageria 2009):

$$\text{Grain harvest index (GHI)} = \frac{\text{Grain yield}}{\text{Grain plus straw yield}}$$

Data were analyzed by analysis of variance and treatment means were compared using the Tukey mean separation procedure. Regression equations were also used wherever necessary.

Results and discussion

Grain yield

Grain yield was significantly influenced by nitrogen timing treatments (Table 1). It varied from 3.87 to 12.65 g per plant with an average value of 9.73 g per plant. Maximum grain yield of 12.65 g per plant was obtained with the N timing treatment of 1/3 at sowing + 1/3 at active tillering and 1/3 at panicle initiation growth stage. The second best N timing treatment in relation to grain yield was 1/2 N applied at the initiation of tillering and remaining half at the panicle initiation growth stage. Grain yield produced at this treatment was 12.32 g per plant. The lowest grain yielding treatment was the entire N applied at sowing. The grain yield at this treatment was 3.87 g per plant. The lowest grain yield at the treatment when the entire N was applied at sowing may be associated with N losses due to volatilization and/or denitrification. There was less time for volatilization or denitrification losses when N was applied in split fractions. Fageria and Baligar (2005) reported that a substantial amount of N may be lost through volatilization and denitrification in upland soils after irrigation. The root system was also not well developed at the beginning of plant growth or seedling growth stage and plants could not absorb the entire N applied at sowing. Split application of N has been reported to increase rice yield in USA and India (Balasubramanian 2002; Walker *et al.* 2006). However, these studies were conducted for lowland or flooded rice and not for upland rice.

Shoot dry weight

Shoot dry weight also significantly influenced by N timing treatments (Table 1). Maximum shoot dry weight of 13.91 g per plant was obtained in the treatment which received 1/2 N at initiation of tillering + 1/2 at panicle initiation. The second treatment which produced maximum shoot dry weight of 12.71 g per plant was 1/3 at sowing + 1/3 at active tillering + 1/3 at panicle initiation growth stage. The minimum shoot dry weight of 4.69 g per plant was produced in the treatment which received whole N at sowing. At this treatment the shoot dry weight was 197% lower compared to highest shoot weight producing treatment, 1/2 N applied at initiation of tillering + 1/2 applied at panicle initiation. Increase in shoot weight is important because it is significantly associated with grain yield (Fageria 2007). Shoot dry weight was having a significant positive quadratic association with grain yield ($Y = -4.4195 + 2.6903X - 0.0949X^2$, $R^2 = 0.9189^{**}$). Hence, about 92% variability in grain yield was due to shoot dry weight. Fageria (2007) reported significant positive association of shoot dry weight with rice grain yield.

Panicle number

Panicle number varied from 2.75 to 7.69 per plant under different N timing treatments (Table 1). Treatment T₃ (1/3 N applied at sowing + 1/3 N applied at active tillering + 1/3 N applied at panicle initiation growth stage) produced maximum panicle followed by T₄ treatment (1/2 N applied at initiation of tillering + 1/2 N applied at panicle initiation growth stage). Treatment T₂ (total N applied at sowing) produced minimum number of panicles. Higher number of panicles in the T₃ and T₄ treatments reflected in higher grain yield in these two treatments (Table 1). Similarly, lower number of panicles in the treatment T₂ reflects in lower grain yield in this treatment. Grain yield was significantly and linearly increased with increasing panicle number ($Y = -0.7337 + 1.7256X$, $R^2 = 0.8873^{**}$). There was about 89% variability in grain yield due to panicle number. Fageria (2007) and Fageria (2009) reported highly significant relation between grain yield and panicle number in rice. Gravois and Helms (1992) reported that optimum rice yield could not be attained without optimum panicle density of uniform maturity.

Grain harvest index

The ratio of reproductive or economical yield to total dry weight is referred to as the grain harvest index (GHI). The GHI is a useful index in evaluating treatment effects on partition photoassimilates to grain within a given environment (Fageria 2009). The GHI varied from 0.45 in the T₂ treatment (whole N applied at sowing) to 0.53 in the T₅ treatment (2/3 N applied at sowing and 1/3 applied at panicle initiation) (Table 1). Fageria (2007) reported that GHI changes with cultivar and with the environmental conditions during the reproductive growth stage. The GHI is an important plant trait for improving grain yield in cereals (Fageria 2007). Furthermore, higher nitrogen use efficiency has also been observed in rice cultivars with high harvest index (Fageria 2007). The GHI values of modern crop cultivars are commonly higher than old traditional cultivars for major field crops (Ludlow and Muchow 1990). Mae (1997) reported that the grain harvest index of traditional rice cultivars is about 0.30 and 0.50 for improved, semi-dwarf cultivars. George *et al.* (2002) reported that upland rice yield can be significantly improved with developing genotypes of higher grain harvest index. The GHI is an important plant trait for improving grain yield in cereals (Fageria 2007). Furthermore, higher nitrogen use efficiency has also been observed in rice cultivars with high harvest index (Bufogle *et al.* 1997).

Conclusions

Rice is the staple food for more than 50% of the world population. In addition, nitrogen fertilizer is a major input for upland rice production in South America and its appropriate management is important in efficient crop production. Inefficient use of N may increase cost of crop production and also cause environmental pollution. Use of adequate N rate with appropriate application time is an important strategy in improving N use efficiency. Based on the results of this study it can be concluded that maximum grain yield of upland rice was obtained with the split application of N. Plant growth like shoot dry weight, and yield component like panicle number significantly and positively associated with grain yield.

Table 1. Grain yield, shoot dry weight, panicle number and grain harvest index as influenced by nitrogen timing treatments.

Nitrogen timing treatment ¹	Grain yield (g/plant)	Shoot dry weight (g/plant)	Panicle number (/plant)	Grain harvest index
T ₁	9.63b	8.83b	6.31b	0.52ab
T ₂	3.87c	4.69c	2.75c	0.45c
T ₃	12.65a	12.71a	7.69a	0.50abc
T ₄	12.32ab	13.91a	7.25ab	0.47bc
T ₅	10.16ab	8.93b	6.31b	0.53a
Average	9.73	9.81	6.06	0.49
F-Test	**	**	**	**
CV(%)	12.8	12.4	10.1	5.8

**Significant at the 1% probability level. Means followed by the same letter in the same column are not significant at the 5% probability level by the Tukey test. ¹T₁ (1/2 N applied at sowing + 1/2 applied at panicle initiation), T₂ (total N applied at sowing), T₃ (1/3 N applied at sowing + 1/3 N applied at active tillering + 1/3 N applied at the panicle initiation), T₄ (1/2 N applied at initiation of tillering + 1/2 N applied panicle initiation), and T₅ (2/3 N applied at sowing + 1/3 N applied at panicle initiation).

References

- Balasubramanian R (2002) Response of hybrid rice (*Oryza sativa*) to levels and time of application on nitrogen. *Indian Journal of Agronomy* **47**, 203-206.
- Bufogle A, Bollich PK, Kovar JL, Macchiavelli RE, Lindau CW (1997) Rice variety differences in dry matter and nitrogen accumulation as related to plant stature and maturity group. *Journal of Plant Nutrition* **20**, 1203-1224.
- Dobermann A, Fairhurst T (2000) Rice: Nutrient disorders & nutrient management. IRRI, Philippines, PPI, USA and PPIC, Canada.
- Fageria NK (2002) Nutrient management for improving upland rice productivity and sustainability. *Communications in Soil Science and Plant Analysis* **32**, 2603-2629.
- Fageria NK (2007) Yield physiology of rice. *Journal of Plant Nutrition* **30**, 843-879.
- Fageria NK (2009) The Use of Nutrients in Crop Plants. New York: CRC Press.
- Fageria NK, Baligar VC (2005) Enhancing nitrogen use efficiency in crop plants. *Advances in Agronomy* **88**, 97-185.
- Fageria NK, Slaton NA, Baligar VC (2003) Nutrient management for improving lowland rice productivity and sustainability. *Advances in Agronomy* **80**, 63-152.

- George T, Magbanua R, Garrity DP, Tubana BS, Quiton J (2002) Rapid yield loss of rice cropped successively in aerobic soil. *Agronomy Journal* **94**, 981-989.
- Gravois KA, Helms RS (1992) Path analysis of rice yield and yield components as affected by seeding rate. *Agronomy Journal* **88**, 1-4.
- Ludlow MM, Muchlow RC (1990) A critical evaluation of traits for improving crop yields in water-limited environments. *Advances in Agronomy* **43**, 107-153.
- Mae T (1997) Physiological nitrogen efficiency in rice: Nitrogen utilization, photosynthesis, and yield potential. *Plant Soil* **196**, 201-210.
- Raun WR, Johnson GV (1999) Improving nitrogen use efficiency for cereal production. *Agronomy Journal* **91**, 357-363.
- Walker TW, Martin SW, Gerard PD (2006) Grain yield and milling quality response of two rice cultivars to top-dress nitrogen application timings. *Agronomy Journal* **98**, 1495-1500.

Pasture fertilisation with sulfur enhanced fertilizer

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Abstract

An evaluation of a Sulfur Enhanced Fertilizer (Thiogro) fertilizer (MAP12) was undertaken on a native pasture oversown with clover near Armidale, NSW, Australia from August 2007 to November 2008. Fertilizers (Single superphosphate (SSP), mono-ammonium phosphate (MAP), pastille DAPS (pastille) and Sulfur enhanced mono-ammonium phosphate 12 (MAP12)) were top dressed onto the sward and four harvests taken over the period. SSP and MAP12 produced higher clover yields than MAP and pastille DAPS. MAP12 was superior to SSP, particularly at the later harvests. This is an important result as clover growth is essential in the pasture both to contribute fixed N and for animal protein. Addition of S fertilizers increased the uptake of S in all treatments, except pastille DAPS. Highest uptake was with MAP12. Calculation of apparent fertilizer recovery ($(S \text{ uptake in S treatment} - S \text{ uptake in MAP treatment}) / S \text{ applied}$) showed a recovery of 16% from SSP, 32% from MAP12 and no recovery from DAP pastille. The increased yield resulting from S application resulted in an increase in the apparent recovery of fertilizer P.

Key Words

Single superphosphate, elemental sulfur, oxidation, leaching.

Introduction

Elemental S is an almost ideal fertilizer as it contains 100% nutrient. The elemental S must be oxidized to sulfate (SO_4) before it is available to plants and since microorganisms carry out this process it is moisture and temperature dependent; as is crop demand for S. The rate of oxidation is also dependent on the particle size of S. This means that there is great scope to manage the release rate of SO_4 to the plant to maximize plant uptake and minimize losses by surface runoff and leaching. Research carried out by Blair *et al.* (1971) has shown that plants require S and P early in growth and that S oxidation rates are enhanced by intimate mixing of P and elemental S (Lefroy *et al.* 1995), which makes S inclusion into P containing fertilizers attractive. Shell invented the "Thiogro" process in 2001 to include microfine elemental S into DAP and MAP and a patent for this was filed in 2003 (International Publication Number WO 2004/043878 A1). A significant feature of the process is that the elemental S is finely divided and is distributed throughout the fertilizer granule. Sulfur oxidation from Thiogro SEF has been determined in plant growth chambers at the University of New England, Armidale using a carrier free $Ca^{35}SO_4$ reverse dilution technique. Ryegrass (*Lolium perenne*) and Rhodes grass (*Chloris gayana*) were grown at temperatures of 22/14 °C and 34/26 °C (14 hour day/10 hour night) respectively, for 9 weeks. At the end of the 9 week growth period an average of 23.6% of fertilizer S was recovered in the plant tops from DAP and MAP based Thiogro with no significant effect of temperature. This compares with 73.2% from gypsum in Rhodes grass and 54.1% in ryegrass. These results demonstrated the metered oxidation of the microfine elemental S at the start of growth, leaving more S for uptake at a later stage of development. However field studies were necessary to confirm release and potential benefits of Thiogro SEF.

Methods

Site and Preparation

The field trial was conducted at the University of New England Newholme Field Research Station approximately 15 km north of Armidale. The site (Smiths Rd) had little history of fertilizer application and as a consequence, native species (eg. *Bothriochloa macra* (Redgrass), *Austrodanthonia spp.* (Wallaby Grass) *Dichanthium sericium* (Queensland bluegrass), *Themeda australis* (Kangaroo Grass), *Poa sieberana* (Tussock Grass)) dominated the pasture composition. The native grasses on the site were mowed to approximately 30 mm and glyphosate (Roundup®) applied to initiate a chemical fallow prior to topdressing the fertilizers. Initial soil analysis indicated that S (KCl-40 S - 2.1 mg/kg) and Colwell P (3.7 mg/kg) concentrations were limiting. Soil pH was 6.1 in water.

Experimental design and fertilizer treatments

The 2m x 4m plots were marked out in a randomised block design with 4 replicates. The replicates were

blocked down the slope to allow lateral movement of nutrient to be removed as a blocking factor if necessary. There were 4 different fertilizer treatments (Table 9).

Table 9. Analysis of fertilizers used

Fertilizer	N	P	Total S	Sulphate S	Elemental S
Single superphosphate (SSP)	0	8.5	11.0	11.0	0
Mono-Ammonium Phosphate (MAP)	11.0	18.2	1.6	1.6	0
Pastille DAPS (pastille)	16.2	16.6	11.3	1.3	10.0
Sulphur Enhanced Mono-Ammonium Phosphate 12 (MAP12)	11.7	15.1	11.6	3.8	7.8

Sowing and sampling

Applications of basal rates of fertilizer were applied to the plot at the time of sowing to attempt to alleviate the plant nutritional constraints allowing only S response to be observed. N and P in the forms of urea and di-ammonium phosphate (DAP) were added to the S fertilizer treatments to ensure equal amounts of both N (20 kg/ha) and P (15.9 kg/ha) were applied to each plot. Potassium (or molybdenum or boron) deficiency was suspected by day 86 of the trial, so basal applications of all suspected nutrient limitations were applied. Potassium was applied at 50 kg K/ha (as KCl), molybdenum was applied at 0.2 kg Mo/ha (as ammonium molybdate) and boron was applied at 1 kg B/ha as boric acid. Nusiral white clover (*Trifolium repens* cv. Nusiral), Seaton Park subterranean clover (*Trifolium subterraneum* cv. Seaton Park) and USA red clover (*Trifolium pratense* cv. USA) were broadcast sown over the plots at 4 kg/ha, 8 kg/ha and 8 kg/ha respectively. Water was applied to initiate germination.

The fertilizers were applied on August 21, 2007 and four harvests were carried out when there was sufficient harvestable material in the the mono-ammonium phosphate treatment which occurred 119, 153, 211 and 343 days after fertilizer application. Preceding each harvest, the pasture composition of each plot was visually estimated by three different assessors and averages were used to estimate the proportion of clover.

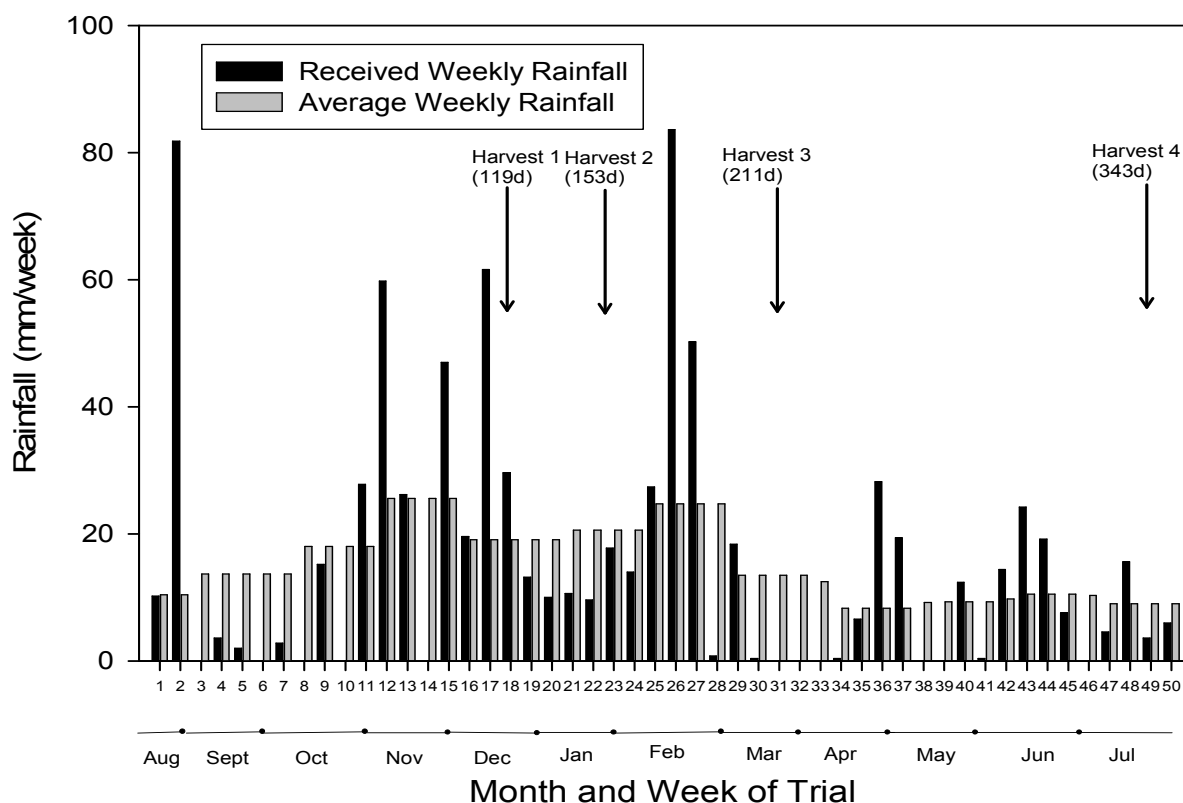


Figure 1. Actual and average rainfall (mm/week) for the trial period.

Climatic conditions

The observed weather conditions were comparable to long term averages recorded for the area and moisture was not thought to be limiting to pasture growth (Figure 1). The high volume rainfall events combined with the coarse textured soil created the potential for leaching of nutrient into the sub-soil or down the slope (Figure 1).

Results

There was a significant S fertilizer treatment effect on total dry matter production ($P>0.05$) with the clover component contributing most of this variation, especially in later harvests (Figure 2). Addition of S fertilizers increased the uptake of S in all treatments, except DAP pastille (Table 10). Highest uptake was with MAP12. Calculation of apparent fertilizer recovery ($(\text{S uptake in S treatment} - \text{S uptake in MAP treatment}) / \text{S applied}$) shows a recovery of 16% from SSP, 32% from MAP12 and no recovery from DAP pastille (Table 10). Apparent recovery of P reflected that of S, with plants that were less limited by S deficiency displaying greater P recovery. When totalled over the period of the trial, MAP12 produced more clover growth than SSP; however, SSP displayed more rapid early dry matter production (Figure 2).

Table 10. S uptake (kg/ha) and apparent fertilizer recovery (S or P uptake in S treatment – S or P uptake in MAP treatment)/ S or P applied) from the S fertilizers applied.

Treatment	S uptake (kg/ha)	Apparent % fertilizer S recovery	Apparent % fertilizer P recovery
DAP past	3.44 a	0 a	34.7 a
MAP	3.65 a	0 a	35.7 a
SSP	5.05 b	16 b	40.4 b
MAP12	6.38 c	32 c	50.8 c

Numbers followed by the same letter are not significantly different according to DMRT.

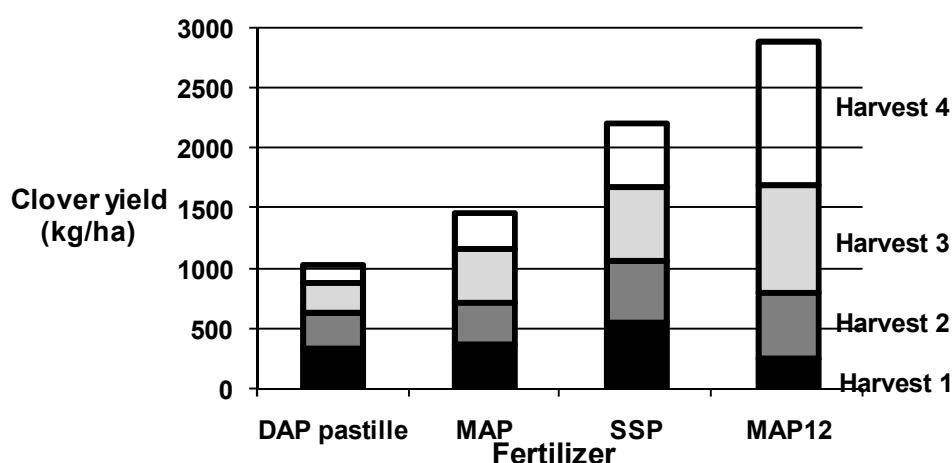


Figure 2. Effect of fertilizer on clover yield at each harvest. Treatments are di-ammonium phosphate with S^o pastilles (DAP pastille) mono-ammonium phosphate (MAP), single superphosphate (SSP), and mono-ammonium phosphate with S in granule (MAP12).

Discussion

The relatively rapid dry matter production by the SSP treatment in early harvests declined with time. In contrast, the MAPS treatment continued to increase harvestable dry matter resulting in greater total dry matter production (Figure 2). Total S uptake was also higher from MAP12 than SSP most likely due to leaching of SO_4 from the SSP treatment two weeks after application (Table 2, Figure 1). The predominant reason for the greater cumulative uptake by clover in the MAPS treatment was that the SO_4 ion, as it exists in SSP, is susceptible to leaching (Blair 1971). It is thought that the MAPS treatment displayed twice the apparent fertilizer S recovery as SSP due to its leaching resistant or slow release properties (Table 2). The coarse textured soil, low adsorption capacity and high initial rainfall of this experimental environment

resulted in the potential for losses laterally and vertically down the soil profile. In leaching environments, SO_4 sources have commonly produced high yields in the early stages of trials, with little residual value, whereas S° sources have been observed to have modest initial yields but greater residual value. On the Northern Tablelands, Jones *et al.* (1969) reported gypsum treatments (44.8 kg S/ha) were S deficient after 11 months. In the present trial S deficiency symptoms were observed in the SSP treatment (applied at 10 kg S/ha) after 4 months. The findings of this experiment are complemented by the literature in reporting greater S uptake from S° fertilizer sources in comparison to SSP under leaching conditions.

The S° pastilles are large particles, with a smooth surface. They are formed from molten S° and are designed to resist water infiltration and dusting during transport. As a result the pastilles have a very low specific surface area and subsequently low oxidation rates (Germida and Janzen 1993). This is because the oxidising microbes require direct contact with the S° surface to enable oxidation (Vogler and Umbreit 1941). The total S uptake data indicates that very little, if any S° was oxidised and made available to the plant during the trial period (Table 2) with implications for total clover dry matter production (Figure 2). It is therefore concluded that due to the low S° specific surface area, S from the pastille treatment was relatively unavailable during the growing period of the trial. The pastille treatment is therefore not recommended for application in the field.

Increased availability of S in limiting conditions allows for improved utilisation of available P. The increased yield resulting from S application resulted in an increase in the apparent recovery of fertilizer P (Table 10).

Conclusion

The advantages of S° fertilizers over SO_4 sources has been clearly demonstrated in soils where there is potential for leaching to occur. The present trial indicated that apparent fertilizer recovery can increase from 16% to 32% over a 15 month period when S° is used instead of the industry standard SSP. However, not all S° fertilizers achieve these benefits. The DAP pastille treatment tested was not observed to be any different from the control due to the large particle size of the S° (low specific surface area). The results indicate the potential for increased fertilizer efficiency and increased production with the use of S° fertilizers in leaching environments.

References

- Blair G (1971) The sulphur cycle. *The Journal of the Australian Institute of Agricultural Science* **37**, 113-121.
- Germida J, Janzen H (1993) Factors affecting the oxidation of elemental sulfur in soils. *Fertilizer Research* **35**, 101-114;.
- Jones MB, Ruckman JE (1969) Effect of particle size on long-term availability of sulfur on annual-type grasslands. *Agronomy Journal* **61**, 936-939.
- Lefroy RDB, Sholeh, Blair GJ (1995) The influence of S and P placement, and S particle size, on elemental S oxidation and the growth response of corn. *Australian Journal of Soil Research*, (submitted).
- Vogler KG, Umbreit JW (1941) The necessity for direct contact in sulphur oxidation by *Thiobacillus thiooxidans*. *Soil Science* **51**, 331-337.

Phosphorus availability and plant production in a Ferralsol from South Brazil

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Abstract

The use of phosphate fertilizer has promoted changes in phosphorus fractions and availability in soil, that highlights the requirement of more studies to understand phosphorus dynamics in soil, and to develop cultivation strategies to increase crop grain yield under phosphate fertilization. The work aimed to evaluate changes in soil phosphorus availability in sequential crop seasons, under effects of phosphate fertilizer sources and cover crop plants. The experiment was carried at Technological Federal University of Paraná, Dois Vizinhos, PR, Brazil. The soil is a Ferralsol, with high level of available P. Experimental design was a factorial 3x8, in randomized blocks, with three replicates and 5x5 m plots. Treatments were composed of natural phosphate and soluble phosphate, and a control. During winter season, the seven cover crops were: vetch, white lupin, radish, ryegrass, black oat, clover and pigeon pea, and a witness with no cover crop. Brazilian Ferralsol, with high level of available P, does not increase plant grain yield with sources of phosphate fertilization. Available P in soil changes markedly with phosphate fertilization, especially in the surface layer (0-5 cm). Important results are expected in soil P availability after winter cover crops.

Key Words

Soluble phosphate, natural phosphate, cover crops, organic acids

Introduction

The use of soil conservation systems, like no-tillage, besides the promotion of better productivity, maintain the environment in a more stable condition, but it causes changes in the dynamics of organic matter and nutrients in soil. No-till has produced great changes in phosphorus (P) fractions in soil, increasing organic fractions and accumulating organic and inorganic P in near surface layers, as result of no mobilization or from the releasing of organic compound that can compete for P adsorption sites in soil (Rheinheimer 2000).

Absorption of P by plants is dependent of the stored P in soil solid phase and of the releasing index to soil solution (Tisdale *et al.* 1985). Phosphorus concentration in soil solution is called intensity factor, and the amount stored in solid phase, linked to adsorption sites and possibly released to soil solution when that fraction is depleted, is called quantity factor (Novais & Smyth 1999). However, the quantity factor is composed of P fractions of different releasing kinetics, that do not permit a simple correlation between the factors intensity and quantity, to estimate the availability of this nutrient for plant absorption. On this way, it is important to know the forms of P in soil solid phase, their dynamic behavior, and the possible contribution to maintain the available levels for plants.

Tropical and subtropical soils, predominant in Brazil, are normally very weathered soils, with great amounts of kaolinite and oxides, with more than 25% of them being very deficient in available P (Sanchez & Logan 1992). The content of total P and its distribution in fractions varies according to parent material and soil management practices, that makes the P availability very variable in each soil type, region, or management practices adopted.

When a phosphate fertilizer is applied to soil, physical-chemical reactions occurs, that promotes incorporation of phosphate into complex substances, that control the availability of P in soil (Kaminski & Peruzzo 1997). There is a necessity, therefore, to better understand the dynamics of P associated to organic compounds production and decomposition in soil, on the way to develop management strategies to maintain or increase crop grain yield, maximizing the use of P linked to these compounds (Rheinheimer 2000).

The work aimed to evaluate changes in soil phosphorus availability in sequential crop seasons, under effect of phosphate fertilizer sources and cover crop plants. However, only the first season's results are reported here.

Material and Methods

Present work was carried at Technological Federal University of Paraná, Dois Vizinhos, PR, Brazil, located in South Brazil, at latitude 25°42'S, longitude 53°08'W and altitude of about 561 m. The soil of the

experimental area is a Ferralsol (WRB-FAO 1998). Soil chemical analysis is presented on Table 1. It shows that soil P level is classified as high and base saturation is good for this soil, from surface to 20 cm depth layer.

Before the experiment was established, the area was cultivated under no-tillage system for seven years, with commercial crops over the summer, like corn and soybean, and cover crops over the winter, like vetch and oat.

The experiment began in December, 2008, with bean planting. Experimental design was a factorial 3x8 in randomized blocks, with three replicates and 5x5 m plots. Treatments on the summer bean crop were: natural phosphate (NP, 9% of soluble P₂O₅) and soluble phosphate (SPS, 17% of soluble P₂O₅), applied at recommended rate for the crop (135 kg of P₂O₅/ha), and control (witness) without phosphate. Potassium fertilization was applied at sowing (40 kg of K₂O/ha) and nitrogen was applied 20 days after germination (40 kg of N/ha).

Table 1. Chemical soil results before experiment establishment in the summer of 2008/2009. UTFPR, Dois Vizinhos, PR, Brazil.

Depth layer	pH CaCl ₂	OM	P (resin)	Al ³⁺	H+Al	Ca ²⁺	Mg ²⁺	K ⁺	V
---- cm ----		g/dm ³	mg/dm ³	----- cmol _c /dm ³ -----					%
0-5	5.4	40.2	8.11	0.00	3.42	5.40	2.69	0.50	71.5
5-10	5.2	40.2	9.73	0.00	3.68	5.62	2.98	0.28	70.7
10-20	5.0	26.8	4.80	0.08	3.97	4.32	2.13	0.13	62.4

Bean dry mass production at flowering, and grain yield were measured. Dry mass was determined with samples dried at 65°C for 72 hours. After the crop material was milled through a 2 mm sieve, it was evaluated for nutrient tissue accumulation, by Tedesco *et al.* (1995) methodology. Grain yield was determined by harvesting the plot central area, and after grain separation, it was weighed and corrected to 13% moisture. During the following winter season, cover crops were planted on that area, being: vetch (*Vicia sativa*), white lupin (*Lupinus albus*), radish (*Raphanus sativus*), ryegrass (*Lolium multiflorum*), black oat (*Avena strigosa*), clover (*Trifolium repens*), pigeon pea (*Cajanus cajan*), and a witness without a cover crop. The cover crops were planted in May, 2009. Grass cover crops received 40 kg of N/ha 20 days after germination. On the cover crops, dry mass production was measured at flowering and nutrient tissue accumulation, with the same methodology used for bean.

Soil P availability was evaluated before experiment establishment, as table 1, and after each crop season, in the depth layers 0-5, 5-10 and 10-20 cm. Available P was measured with anion exchange resin methodology. The data were submitted to ANOVA analysis and significant means were compared by t test (LSD) at 5%, by the program SAS 8.2 (SAS Institute 2001).

Results and Discussion

The original soil showed a high level of available P in all evaluated layers, from surface to 20 cm, which probably was enough for a good bean development, as this crop does not demand high amounts of P from the soil (Embrapa 2005). The data in table 2 illustrates this, because the amount of P accumulated in plant tissue at flowering stage was about 5.0 kg/ha, a very low quantity compared to the amount applied via fertilizer. However, the main idea of the work is to evaluate what will happen with the amount of P applied via fertilizer after the cover crop winter season, this explains why the higher fertilization rate was used before bean cultivation. Dry mass accumulation in plant tissue and other nutrients evaluated does not differ statistically between sources of P.

Table 2. Dry mass production and nutrient accumulation on bean plant tissue under sources of phosphate fertilizer. UTFPR, Dois Vizinhos, PR, Brazil.

Treatment	Dry mass kg/ha	Nutrients on plant tissue (kg/ha)				
		N	P	K	Ca	Mg
Witness	1404 ^{ns}	46.0 ^{ns}	4.3 ^{ns}	40.1 ^{ns}	31.0 ^{ns}	7.2 ^{ns}
Super Phosphate Simple	1507	50.1	5.6	42.6	31.9	8.9
Natural Phosphate	1281	39.8	4.6	36.0	27.6	7.8
CV (%)	17.9	24.9	20.8	33.9	22.4	15.1

^{ns} Not significant by t test (LSD) at 5% of error probability.

Bean grain yield was increased a little bit by phosphate application (Figure 1), although the difference was not significant statistically. However, it is important to emphasize that the bean crop season of 2008/2009 was a drought, with three months of almost no precipitation, between December/2008 and February/2009, this had a negative influence on the results of grain yield. The potential production is much higher than that obtained in the experiment, mean of 1295 kg/ha, as farmers of the same region had obtained mean grain yield of about 1800 kg/ha in years of normal precipitation.

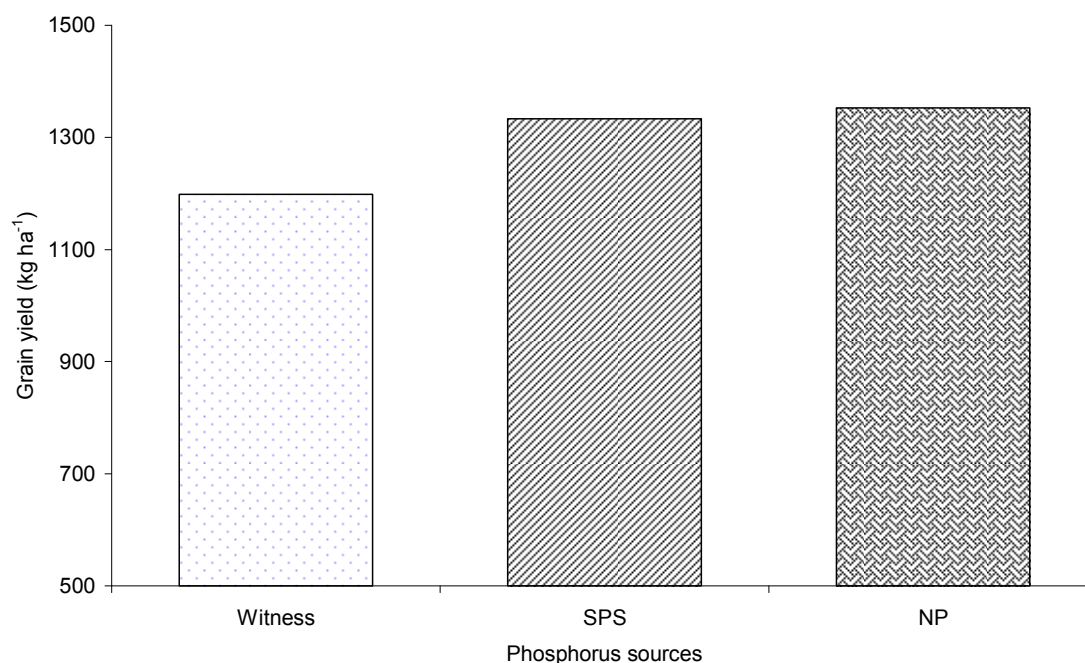


Figure 1. Bean grain yield under sources of phosphate fertilization, in a Ferralsol from South Brazil. UTFPR, Dois Vizinhos, PR. (Difference not significant by t test (LSD) at 5%).

Soil available P increased substantially under phosphate fertilization, especially on the 0-5 cm layer, with higher availability with NP fertilization, compared to SPS fertilization and witness (Table 3). In deeper layer, small changes were observed in this first crop season, more significant results are awaited in the next summer season, once cover crops were cultivated in the area. Cover crop species were used to promote changes in P availability, by releasing organic compounds in soil, from roots or shoot dry mass, that could act by competing with phosphate for the soil adsorption sites, so increasing available P in soil solution (Guppy *et al.* 2005).

Table 3. Levels of available phosphorus, by resin of anion exchange, in soil layers after bean cultivation, under sources of phosphate fertilizers. UTFPR, Dois Vizinhos, PR, Brazil.

Depth layer	Without fertilization	Natural phosphate (NP)	Soluble phosphate (SPS)
---- cm ----	-----	mg/dm ³ -----	-----
0-5	8.18	16.50	12.47
5-10	2.66	3.93	4.71
10-20	1.39	1.79	2.15

Higher amounts of dry mass were obtained with white lupin, independent of fertilizer use (Table 4). Ryegrass and black oat has produced great dry mass amount, also. Pigeon pea did not growth in the winter season, because it is susceptible to low temperatures (frost occurred in the period), which explains the amount produced, being similar to witness. Clover was not efficient in dry mass production, and vetch and radish produced good amounts of dry mass for this region and soil type. It will be interesting to see if those species were efficient in solubilizing soil P, by what will be evaluated in the next months (November-December/2009).

Table 4. Cover crops dry mass production under phosphate fertilization during the winter season of 2009. UTFPR, Dois Vizinhos, PR, Brazil.

Cover crops	Witness	Natural phosphate	Super Phosphate Simple	Mean
	----- kg/ha -----			
Witness	2213 d*	2613 bc	1933 b	2253 e
Vetch	4480 cd	4680 abc	4907 b	4689 d
White lupin	13627 a	9293 a	14373 a	12431 a
Radish	6840 bc	7853 a	5827 b	6840 cd
Ryegrass	8853 b	9253 a	11760 a	9956 b
Black oat	6093 bc	7267 ab	11200 a	8187 bc
Clover	2040 d	1667 c	1893 b	1867 e
Pigeon pea	2027 d	1813 c	2467 b	2102 e
CV (%)	35.8	49.3	37.2	39.3

* Values followed by the same letter in columns are not different by t test (LSD) at 5% of error probability.

Conclusion

Brazilian Ferralsol, with a high level of available P, did not increase plant grain yield with sources of phosphate fertilization, however, the summer crop season was very dry. Available P in soil changes by phosphate fertilization, especially in the surface layer (0-5 cm). Important results are expected by the analysis of soil P availability after winter cover crops.

References

- Embrapa (2005) *Cultivo do Feijão Irrigado na Região Noroeste de Minas Gerais*. EMBRAPA ARROZ E FEIJÃO. Sistemas de Produção, n.5
- Guppy CN, Menzies NW, Moody PW, Blamey FPC (2005) Competitive sorption reactions between phosphorus and organic matter in soil: a review. *Australian Journal of Soil Research* **43**, 189-202.
- Kaminski J, Peruzzo G (1997) *Eficácia de fosfatos naturais reativos em sistemas de cultivo*. Santa Maria. NRS – Sociedade Brasileira de Ciência do Solo, 31p.
- Novais RF, Smyth TJ (1999) *Fósforo em solo e planta em condições tropicais*. Viçosa: UFV, 399p.
- Rheinheimer DS (2000) *Dinâmica do fósforo em sistemas de manejo de solos*. 2000. 210f. Tese (Doutorado em Ciência do Solo) - Universidade Federal do Rio Grande do Sul. Porto Alegre.
- Sanchez PA, Logan TJ (1992) *Myths and science about the chemistry and fertility of soils in the tropics*. Madison: ASA/SSSA, p.35-46.
- SAS Institute (2001) *SAS user's guide: Statistics*, Ver 8.2; Cary, NC.
- Tedesco MJ, Gianello C, Bissani CA, Bohnen H, Volkweiss SJ (1995) *Análises de solo, plantas e outros materiais*, 2.ed. Porto Alegre, Universidade Federal do Rio Grande do Sul, 174p.
- Tisdale SL, Nelson WL, Beaton JD (1985) *Soil fertility and fertilizers*. 4ª ed., New York: Macmillan, 754p.
- Vilela DT (2006) *Pinus e micorriza: uma importante associação*. Informativo ARESB. Ed. 82.
- WRB-FAO (1998) *World Reference Base for Soil Resources*. Food and Agriculture Organization of the United Nations. ISRIC and ISSS, Rome.

Phytoextraction of phosphorus from Australian dairy pasture soils to reduce environmental loss

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Abstract

The loss of phosphorus (P) from land used for primary production to the environment is of considerable interest for the research and policy fields. Phytoextraction of pasture soil P through management practices such as reducing or omitting P fertiliser application may reduce concentrations and ultimately losses to the environment in surface runoff. The rate of soil P decline when phytoextracted by intensive pasture systems is not known, but preliminary results suggest that the initial soil extractable P concentration, soil buffering properties, P removal rate, P fertiliser rate and time may affect the rate of decline. We investigated the effect of these factors on the rate of P decline on six soils in north-west Tasmania. Olsen, Colwell and CaCl₂ P extractions are being used as agronomic (Olsen and Colwell P) and environmental (CaCl₂) measures of soil P. It is hypothesized that soil characteristics are the main driver behind the rate of P decline and the effects of various properties are being examined.

Key Words

Mining, withdrawal, decline

Introduction

Phosphorus (P) contained in runoff from intensively managed pastures can contribute to eutrophication of surface waters. Surface runoff concentrations are strongly related to soil P concentrations (Sharpley and Rekolainen 1997). Recent surveys in Tasmania and NSW have found that 60-70% of paddocks used for dairying have 2-3 times more P than the agronomic optimum. Soil P concentrations above agronomic optimum represents an unnecessary environmental risk. Strategies need to be developed to reduce soil P concentrations and hence runoff P. Few options for reducing environmental P loss that land owners will readily adopt have been proposed. Omitting P fertiliser application to high P concentrated soils may be one method of reducing the risk of P loss that could be readily adopted.

Research has been undertaken concerning phytoextraction of P concentrations under cropping systems. The emphasis has been on monitoring crop yield during the withdrawal stage (Paris *et al.* 2004), and is usually restricted to a limited range of soil types and initial P concentrations. Research was undertaken in the Netherlands concerning enriched grassland soils through omitting P application (VanderSalm *et al.* 2009), however the variety of soils used were small. The most broad source of P decline data comes from descriptions of P decline of control treatments i.e. (Roberts *et al.* 1994; Burkitt *et al.* 2002a), however high P concentrated soils are not usually included in these treatments. Little emphasis has been placed on the rate of P decline (mg/kg) across a range of initial soil P concentrations, soil types and characteristics, which may be the drivers under pasture systems.

Methods

Site management and soil characterisation

Six field sites were established on rain-fed commercial grazing properties across the major grazing areas of north and north-west Tasmania. All sites were used for permanent pasture, comprising predominantly perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), received a mean annual rainfall of 800–1000 mm (BOM 2005) and were grazed rotationally with varying stocking rates by dairy or beef cattle.

Treatments

At each site four soil P categories (defined by Olsen P) were established to represent typical paddock concentrations as follows; low ≤ 15 mg/kg, medium 16–30 mg/kg, high 31–40 mg/kg, and very high ≥ 41 mg/kg. In a fully factorial design, four P fertiliser rates were applied every six months, all treatments being replicated three times. The P fertiliser treatments were 0, 0.5, 1 and 2 times estimated P maintenance rates, according to site P buffering properties and soil P concentration, and maximum rates varied between 20 and 50 kg P/ha/yr between sites.

Soil sampling and analyses

Fifteen soil cores were sampled from each plot to a 100 mm depth for all treatments immediately before fertiliser application. To date, samples have been taken every 6 months from May 2005 until November 2009. The samples were analysed for Colwell (Colwell 1963), Olsen (Olsen *et al.* 1954) and CaCl_2 extractable P (Murphy and Riley 1962).

The data were analysed using a mixed model beginning with the full model containing all terms and interactions and subsequent elimination of non-significant terms.

Results

The Olsen P data for the initial two years are shown in Figure 1. There was an overall decreasing trend with time. There was an interaction between initial P concentration and time, with higher initial P concentrations declining more rapidly than lower ones.

For Olsen P, the very high concentrated soils declined by 2.5075 mg/kg per six months; high by 1.4281 ($= -2.5075 + 1.0794$) mg/kg per six months, but was not significantly different from the very high rate ($P=0.0943$); medium declined by 0.3602 ($= -2.5075 + 2.1473$) mg/kg per six months; and low declined by 0.0757 ($= -2.5075 + 2.4318$) mg/kg per six months, which was not significantly ($P<0.05$) different from zero. Thus Olsen P declined only for high and very high P concentrated pasture soils.

The inclusion of low PBI soils in this investigation highlights the environmental risk of fertilising these soils. Interestingly, Olsen and Colwell P concentrations at Site 3 could not be built beyond the initial concentrations of 23 and 30 mg/kg respectively, even after application of 250 kg P/ha. We hypothesize that this is because P applied to these soils leached beyond the top 100 mm due to the low P buffering. The other sites had Olsen and Colwell P concentrations ranging from 51-111 and 256-433 mg/kg, respectively for the same treatments.

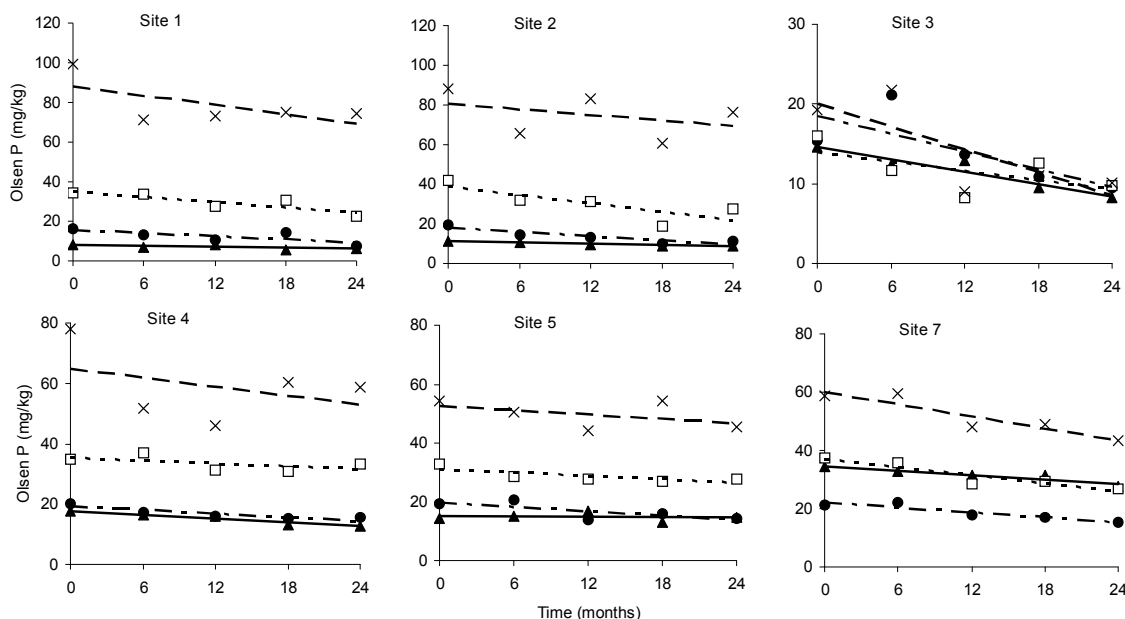


Figure 1. Two year decline in Olsen P concentration for the low (—▲—), medium (—●—), high (—□—) and very high (—x—) categories when fertiliser P is omitted at each site. Note that the scale of the y-axis varies.

Table 1. Selected chemical properties measured from the surface of pasture soils (0–100 mm) sampled from six field sites located in north and north-west Tasmania, prior to P fertiliser treatment.

Characteristic	Site					
	1	2	3	4	5	7
pH (CaCl ₂)	5.4	4.8	3.9	4.9	4.8	4.6
Olsen P (mg/kg)	11.9	11.9	16.3	18.4	18.3	37.2
Colwell P (mg/kg)	40	39	30	43	69	72
Total P (mg/kg)	1287	418	314	406	1680	326
Organic P (mg/kg)	971	363	265	222	1019	248
Organic C (g/kg)	95	28	114	26	60	87
CEC (cmol _c /kg)	21	9	19	5	24	13
Ox-Al (mg/kg)	5849	2589	286	676	5186	797
Ox-Fe (mg/kg)	4680	4030	774	2340	12320	693
PBI _{+ColP} ^A	519	232	6	70	430	71
PBI _{+ColP} category ^B	High	Moderate	Extremely Low	Very Low	High	Very Low

^A Phosphorus buffering index_{X+ColP} (Burkitt *et al.* 2002b).

^B Phosphorus buffering index category (Moody 2007).

Conclusion

Preliminary results suggest the higher the initial P concentration, the greater the initial rate of decline. In addition there is a significant P fertiliser rate effect on rate of P decline. In addition to further monitoring, in the future we will be investigating the environmental implications of various fertiliser P rates, in particular withholding fertiliser P on high P concentrated soils.

References

- BOM (2005) 'Average Annual Rainfall 1961-1990.' (Bureau of Meteorology: Tasmania) 26/03/2007
- Burkitt LL, Gourley CJP, Sale PWG (2002a) Changes in bicarbonate-extractable phosphorus over time when P fertiliser was withheld or reapplied to pasture soils. *Australian Journal of Soil Research* **40**, 1213-1229.
- Burkitt LL, Moody PW, Gourley CJP, Hannah MC (2002b) A simple phosphorus buffering index for Australian soils. *Australian Journal of Soil Research* **40**, 1-18.
- Colwell J (1963) The estimation of the phosphorus fertiliser requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **6**, 105-120.
- Moody PW (2007) Interpretation of a single-point P buffering index for adjusting critical levels of the Colwell soil P test. *Australian Journal of Soil Research* **45**, 55-62.
- Murphy J, Riley JP (1962) A modified single-solution method for the determination of phosphate in natural waters. *Analytical Chimica Acta* **27**, 31-36.
- Olsen S, Cole C, Watanbe F, Dean L (1954) 'Estimation of available phosphorus in soils by extraction with sodium bicarbonate.' (U.S. Government Printing Office: Washington, DC).
- Paris P, Gavazzi C, Tabaglio V (2004) Rate of soil P decline due to crop uptake. Long-term curves of depletion. *Agricoltura Mediterranea* **134**, 236-245.
- Roberts AHC, Sinclair AG, Johnstone PD, Risk WH, Smith LC, O'Connor MB, Nguyen L, Morton JD, Shannon PW (1994) Changes in soil Olsen phosphorus over six years with annual applications of triple superphosphate or reactive phosphate rock (Sechura). *New Zealand Journal of Agricultural Research* **37**, 229-237.
- Sharpley AN, Rekolainen S (1997) Phosphorus in Agriculture and Its Environmental Implications. In 'Phosphorus Loss from Soil to Water'. (Eds H Tunney, OT Carton, PC Brookes, AE Johnston). (CAB International: Oxon, UK).
- VanderSalm C, Chardon WJ, Koopmans GF, Middlekoop JCv, Ehlert PAI (2009) Phytoextraction of phosphorus-enriched grassland soils. *Journal of Environmental Quality* **38**, 751-761.

Phytomass partition of sunflower silage, under boron and calcium fertilization

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Abstract

This work aimed to determine the distribution of sunflower phytomass and the effect/cause relation between the variables analyzed in silage production, under calcium and boron fertilization. The experiment was carried at Federal Technology University of Paraná, *Campus* Dois Vizinhos, PR, Brazil, from September, 2008 to April, 2009. The soil is a Nitossolo Vermelho Distroférrico úmbrico by Brazilian classification and Ferralsol by WRB. Treatments were composed of: (i) Witness; (ii) 2000 g of B/ha applied via soil at sowing; (iii) 250 (iv) 500 (v) 750 and (vi) 1000 g of Ca/ha applied in leaves; (vii) 250 (viii) 500 (ix) 750 and (x) 1000 g of B/ha applied in leaves. Leaf application was made by dissolving each treatment and applying in 200 litres (L)/ha solution, with the respective treatments, about two weeks before flowering stage. Plants were harvested to produce silage when grains were with 35% humidity. Boron and calcium fertilization does not change the phytomorphologic variables analyzed in this experiment. Inside the variables, dry phytomass of seeds was the most important in silage production, with a direct correlation with final yield in the field. Indirectly, the variables dry phytomass of stem + achene and green leaves were responsible for increasing silage yield, also.

Key Words

Helianthus annuus L., ensilage, crop production, micronutrients.

Introduction

Sunflower is an oleaginous plant, responsible for producing excellent edible oil. This crop has a great potential to increase the cultivation in Brazilian agricultural areas, especially because is resistant to cool and dry climate conditions, when compared to other crops used for silage in Brazil, like corn and sorghum. Calcium (Ca) and boron (B) are two important nutrients for apical bud and root end development, since are nutrients of low internal plant mobility, being not capable to retranslocate after synthesis in plant compounds. Their main function in higher plants is structural, as component of cell wall and plasma membrane. Without them, shoot and root growth are strongly inhibited. Calcium is normally provided efficiently from soil, especially when the pH is high. However, boron necessity is higher than other species in sunflower, and this crop is not efficient to absorb B from soil, being possible to observe losses of 15 to 40% in grain yield when cultivated in soils with lower levels of B (Souza *et al.* 2004). The possible ways to apply boron on plants are: soil borate fertilization, on the sow crop line or spread before sowing; and leaf application, applied alone or together with crop defensives. It is recommended to apply 1.0 to 2.0 kg of B/ha in soils with deficiency (Castro 2006). Deficiency of B in sunflower promotes growth inhibition and dry mass reduction, reducing, on this way, achene diameter and seed weight, what consequently depletes sugar, oil and starch contents (Bonacin *et al.* 2008). This work aimed to determine the distribution of sunflower phytomass and the effect/cause relation between the variables analyzed in silage production, under calcium and boron fertilization.

Material and methods

The experiment was carried at Federal Technology University of Paraná, *Campus* Dois Vizinhos, PR, Brazil, during the period of September, 2008 to April, 2009. The experimental area is located at latitude 25°44' South, longitude 53°04' West and mean altitude of 520 meters. The climate is classified as mesothermic humid (Cfa) by Koppen (Maak 1968). The soil is a Nitossolo Vermelho Distroférrico úmbrico by Brazilian classification (Bhering *et al.* 2008) and Ferralsol by WRB/FAO (1998). Soil chemical results are presented on Table 1. Soil nutrients availability (P, K, Ca and Mg) are interpreted as high, according to regional recommendations. The genotype used was Agrobela - La Tijereta. Sowing was made at September, 26, 2008, putting three seeds each small line hole, adjusting the population to 50.000 plants/ha by hand after germination. The experimental design was in completely randomized blocks, with three replicates. Plots were composed of six meters long and five seed lines of 0.9 meters spaced, harvesting only the central lines.

Table 1. Results of chemical soil analysis preceding sunflower experiment establishment. UTFPR, Dois Vizinhos, PR, Brazil, 2008.

Depth layer (cm)	pH	CaCl ₂	O.M. (g/dm ³)	P (Mehlich1) (mg/dm ³)	Al ³⁺ (----- cmol _c /dm ³ -----)	H+Al	Ca ²⁺	Mg ²⁺	K ⁺	V %
0-20	5.00		40.21	12.84	0.00	4.28	4.88	2.67	0.73	65.9

Treatments were composed of: (i) Witness (control); (ii) 2000 g of B/ha applied via soil at sowing; (iii) 250 g of Ca/ha applied in leaves; (iv) 500 g of Ca/ha applied in leaves; (v) 750 g of Ca/ha applied in leaves; (vi) 1000 g of Ca/ha applied in leaves; (vii) 250 g of B/ha applied in leaves; (viii) 500 g of B/ha applied in leaves; (ix) 750 g of B/ha applied in leaves; and (x) 1000 g of B/ha applied in leaves. Leaf application was made by dissolving each treatment and applying in 200 litres (L)/ha solution, with the respective treatments, about two weeks before flowering stage. Soil and leaves treatment with boron were made with Sodium Octaborate (20.5% of total B, and 9% of soluble B), considering the safe soluble concentration for leaf application. Calcium treatments were carried with Calcium Chloride PA.

The harvest to ensilage was made at January, 08, 2009, when sunflower grains were at about 35% of moisture. Just one line of five meters of sunflower plants was used in the ensilage process, cutting the plants at about 30 cm from surface. After, one plant each plot was selected to evaluate the composition fractions, segregating stem + achene, photosynthetic green leaves, dead leaves, and seeds. All fractions were dried at 55 °C to determinate dry mass in each fraction. Other harvested plants were crushed in a mill (3-5 cm pieces), and compacted in PVC pipes of 10 cm of diameter and 50 cm long, simulating conditions of silage preparation in the field (called micro-silo). The pipes were stored in laboratory, and opened at June 19, 2009. By the opening process, a sample was taken, and was dried at 55 °C. Variables analyzed were: number of plants per hectare, fresh phytomass per plot, dry phytomass of stem + achene, dry phytomass of green leaves, dry phytomass of dead leaves, dry phytomass of seeds, dry phytomass of milled plants, dry phytomass of silage, number of green leaves, number of dead leaves, mass of micro-silo after compaction, and mass of silage after open the micro-silo. All data were submitted to ANOVA, considering the following statistic parameters: minimum, maximum, mean, variation coefficient and LSD% by Tukey (5%), and multicollinearity test by the Genes software (Cruz 1997).

Results and discussion

ANOVA analysis showed that the variables considered were not significant between treatments (Table 2). On the Table 3 are presented the various fractions analyzed in fresh and dried samples of silage, what shows that fresh plant presents about 33.146 kg/ha, being the great part represented by stem + achene (71.12%), the second most important was the phytomass of seeds (13.35%), phytomass of green leaves in third (11.29%) and the last one was the phytomass of died leaves (4.24%). After the samples be dried at 55 °C, it was possible to observe changes in the proportion of each plant composition. Phytomass of stem + achene represented less than a half of total plant (47.03%) and phytomass of seeds increased significantly (29.29%). Died leaves, once they are almost dried in the field, almost did not lose humidity by 55 °C, then amplified the amount proportional to total plant in three times, responsible for 12.42%, and green leaves maintained the proportion in plant partition.

Table 2. Variation source (FV), values of minimum, maximum, mean, variation coefficient (CV) and least significant difference (LSD by Tukey, 5%), for the variables: number of plants per hectare (NP); fresh phytomass of total plants (FFTP, kg); dry phytomass of stem + achene (MSHC, %); dry phytomass of green leaves (MSF, %); dry phytomass of dead leaves (MSFS, %); dry phytomass of seeds (MSS, %); dry phytomass after plant mill (pre-ensilage) (MST, %); number of green leaves (NFV); number of dead leaves (NFS); micro-silo mass (PMS, %); silage mass after micro-silo opening (MSAA, %); dry mass of silage (MSSI, %).

FV	NP	FFTP	MSHC	MSF	MSFS	MSS	MST	NFV	NFS	PMS	MSAA	MSSI
Minimum	42222.0	6.50	14.07	20.92	70.67	57.49	18.3	5.0	7.0	3.44	1.94	26.77
Maximum	64444.0	12.80	24.45	45.81	115.41	73.05	33.08	18.0	20.0	4.08	3.24	33.33
Mean	52518.5	9.53	19.45	31.34	84.90	63.13	26.03	12.06	13.23	3.72	2.55	29.46
CV (%)	9.90	16.84	13.05	21.01	9.49	5.95	15.79	26.63	24.80	5.56	9.43	3.86
LSD (5%)	15234.6	4.70	7.43	19.27	23.59	10.99	12.03	9.40	9.60	0.60	0.70	3.33

By the data presented on Table 3, total dry mass on the sunflower plants were responsible for about 28.55% of fresh phytomass of silage. Rezende *et al.* (2002) showed that mean sunflower dry mass is 32.83%. Stem + achene were responsible for 18.88% of dry phytomass, green leaves were responsible for 28.47%, died

leaves and seeds presented higher amounts of dry mass, 83.66 and 62.64%, respectively, what was resultant of low humidity by the field harvest. Author results are similar to the present experiment data.

On the Table 4 are presented the direct and indirect effects of dependent variables about main variable (phytomass of silage). It is verified that number of plants per hectare has a direct effect about phytomass of silage, but negative, what means that decreasing the number of plants per hectare will increase plant capacity to incorporate more carbohydrates, and produce more dry mass, because of the stress that is higher between plants when in conditions of higher population density. From all variables considered in the study, the one that presented higher direct effect, and positive, about the phytomass of silage was the dry phytomass of seeds, with correlation value of 0.977. Other variable with direct effect was the dry phytomass after plant mill (0.684). On this way, the maximization of silage dry mass occurs when higher values of seed dry mass are obtained, in expense to other variables.

Table 3. Phytomass of a full plant (PI), phytomass of stem + achene (HC), phytomass of green leaves (FV), phytomass of dead leaves (FS) and phytomass of seeds (SP), percentage of different fractions (%) evaluated in green samples (Green) and dried samples (Dried), and final percentage of dry phytomass (FMS).

	Green %	Green	Dried	Dried	FMS
	%	kg/ha	%	kg/ha	%
PI	100.00	33146.67	100.00	9462.99	28.55
HC	71.12	23574.67	47.03	4450.80	18.88
FV	11.29	3742.47	11.26	1065.49	28.47
FS	4.23	1404.81	12.42	1175.27	83.66
SP	13.34	4423.68	29.28	2771.40	62.64

Table 4. Path analysis of dependent variables number of plants per hectare (NP), fresh phytomass per plot (FMFP, kg), dry phytomass of stem + achene (MSHC, %), dry phytomass of green leaves (MSF, %), dry phytomass of died leaves (MSFS, %), dry phytomass of seeds (FMS, %), dry phytomass after plant mill (MST, %) and dry phytomass of silage (MSS, %).

	NP	FMFP	MSHC	MSF	MSFS	FMS	MST
Direct effect about MSS	-0.617	0.334	-0.343	0.263	0.413	0.977	0.684
Indirect effect via NP	---	-0.163	-0.244	-0.35	-0.034	-0.061	-0.392
Indirect effect via FMFP	0.088	---	0.079	0.009	0.003	-0.126	-0.009
Indirect effect via MSHC	-0.136	-0.081	---	-0.195	-0.058	0.166	0.637
Indirect effect via MSF	0.149	0.007	0.149	---	-0.048	0.119	0.741
Indirect effect via MSFS	0.023	0.004	0.072	-0.076	---	-0.194	0.103
Indirect effect via FMS	0.097	-0.371	0.472	0.443	-0.459	---	-0.238
Indirect effect via MST	0.435	-0.188	-0.127	0.192	0.170	-0.167	---
Total	0.041	-0.288	0.056	0.286	-0.13	0.380	0.285
Determination coefficient	0.495						
Variable residual effect	0.71						

Conclusion

According to statistical correlations, boron and calcium fertilization does not change the phytomorphologic variables analyzed in this experiment. Within the variables, dry phytomass of seeds was the most important in silage production, with a direct correlation with final yield in the field. Indirectly, the variables dry phytomass of stem + achene and green leaves were responsible for increasing silage yield, also.

References

- Bhering SB, Santos HG, Bognola IA, Cúrcio GR, Manzatto CV, Carvalho JW, Chagas CS, Áglío MLD, Souza JS (2008) 'Mapa de solos do Estado do Paraná: legenda atualizada'. (Rio de Janeiro: EMBRAPA/IAPAR).
- Bonacin GA, Rodrigues TJD, Cruz MCP, Banzatto DA (2008) Características morfofisiológicas de sementes e produção de girassol em função de boro no solo. *Revista Brasileira de Engenharia Agrícola e Ambiental* **13**, 111-116.
- Castro C, Moreira A, Oliveira RF, Dechen AR (2006) Boro e estresse hídrico na produção do girassol. *Ciências agrotécnicas* **30**, 214-220.
- Cruz CD (1997) 'Programa GENES - Aplicativo Computacional em Genética e Estatística'. (Editora UFV: Viçosa).

- Maak R (1968) 'Geografia física do estado do Paraná'. (Curitiba: Banco de Desenvolvimento do Paraná).
- Rezende AV, Evangelista AR, Barcelos AF, Siqueira GR, Santos RV, Mazo MS (2002) Efeito da Mistura da Planta de Girassol (*Helianthus annuus* L.), durante a Ensilagem do Capim-Elefante (*Pennisetum purpureum* Schum.) no Valor Nutritivo da Silagem. *Revista Brasileira de Zootecnia* **31**, 1938-1943.
- Souza A, Oliveira MF, Castiglioni VBR (2004) O boro na cultura de girassol. *Semina: Ciências Agrárias* **25**, 27-34.
- WRB-FAO (1998) 'World Reference Base for Soil Resources'. (FAO: Rome).

Pine seedlings development under sources and rates of phosphate fertilization

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Abstract

Phosphorus is an essential element for plant growth, the evaluation of seedling development and the possible phosphate solubilization by the root system, are important ways to evaluate the behavior of this nutrient in soil. The present work aimed to evaluate the growth of pine seedlings, as a function of soluble and slowly soluble phosphate fertilization. Pine seedlings were cultivated in plastic bags with 2 kg of substrate, which was composed of 50% of a clayey soil from subsurface horizon of a Ferralsol, and 50% sand, both mixed uniformly. Treatments were constituted of natural phosphate (NP), soluble phosphate (SPS) and a commercial fertilizer of slow solubility (Basacote[®]), both were applied as half, full and twice the recommended rate for that species. Fertilization with the slow solubility fertilizer Basacote have promoted better seedling growth, resulting in higher stem diameter and plant height after 240 days after germination. However, other morphologic parameters are important to be considered to produce vigorous seedlings with good nutritional conditions for future field adaptation and development.

Key Words

Pinus elliottii, soluble phosphorus, natural phosphate, basacote.

Introduction

One of the main factors that changes plant growth is nutrient availability, mostly, in Brazilian soils, phosphorus (P) availability (Novais and Smyth 1999). Despite the popular knowledge that *Pinus* species cultivated in Brazil have low response to nutritional demands, research has demonstrated that when these plants are cultivated in low fertility soils, their growth is significantly smaller than in high fertility soils, although not presenting any nutritional deficiency symptom. In pine seedlings production, an important factor is the beginning growth, because it is going to interfere in pine development in the field after transplantation. In this way, the use of a nutritional calibrated substrate will contribute to a good seedling development; will result in adequate plant set and initial growth in the field, besides promoting plant resistance to pests and diseases. Phosphorus is an essential element for plant growth, being a component of structural cells, nucleic acids and cell membrane phospholipids, also as metabolic component of energy storage, like ATP. The absorption of P by plants is dependent of the substrate composition and of the solubilization index of it to soil solution (Tisdale *et al.* 1985), which can be changed by the source and way to apply the fertilizers.

Many soil microorganisms, including fungi and bacteria, have the capacity to solubilize phosphates though different ways, especially by organic acids production. These organic acids can compete for soil P with soil adsorption sites, maintaining free P in solution (Guppy *et al.* 2005). The species *Pinus elliottii*, similar to other *Pinus*, has the capacity to create colonies of mycorrhizae fungi in their root system, these colonies contribute to a better soil volume exploitation by the root system and, possibly, solubilize and absorb more P from the soil (Vilela 2006). Sources of phosphate fertilizers of different solubility are normally used in forest areas, at nursery or in the field. Thereby, information about seedling development and solubilization of phosphate and other nutrients by root systems are missing from literature, and are important ways to understand the behavior of the nutrients in the field. Hence, the present work aimed to evaluate the growth of pine seedlings, as functions of rates and sources of phosphate fertilization.

Material and methods

The experiment, with *Pinus elliottii* seedlings production, was carried at Forestry nursery of Technological Federal University of Paraná, Dois Vizinhos, PR, Brazil, located at latitude 25°42'S, longitude 53°08'W and altitude of about 561 m. Experiment was conducted in the year of 2009, with germination on January 20, 2009. Pine seedlings were cultivated in plastic bags with 2 kg of substrate, which was composed of 50% of clay soil from subsurface horizon of a Ferralsol (WRB-FAO 1998), and 50% sand, mixed uniformly. Experimental design was completely randomized, with plots composed of seven pine seedlings, distributed in a bed of 10 x 1 m, with four replicates. A 50% net shade was used to protect the seedlings against solar

incidence in the beginning phase. Irrigation was made manually everyday. Treatments constituted natural phosphate (NP), soluble phosphate (SPS) and a commercial fertilizer of slow solubility (Basacote®), both applied as half, full and twice the recommended rate by that species, and one witness (control) without P fertilizer. The available nutrients composition of Basacote was 13% of N, 6% of P₂O₅ and 16% of K₂O. Natural phosphate (9% of P₂O₅) and soluble phosphate (18% of P₂O₅) were applied in the quantities of P similar to Basacote treatments. Rates of nitrogen and potassium for the witness treatments, NP and SPS were calculated considering the full rate of Basacote (0.78 kg/m³ of N as urea and 0.96 kg/m³ of K₂O as potassium chloride). Total amount of fertilizer in each treatment is described in Table 1.

Table 1. Amount of fertilizer applied in the moment of substrates preparation before pine sowing. UTFPR, Dois Vizinhas, PR, Brazil.

Treatment	Description	Treatment	Description
Witness	No P fertilization	SPS 1x	2.12 kg/m ³ Super Phosphate Simple
NP 0.5x	2.0 kg/m ³ of natural phosphate	SPS 2x	4.24 kg/m ³ Super Phosphate Simple
NP 1x	4.0 kg/m ³ of natural phosphate	BAS 0.5x	3.0 kg/m ³ of Basacote
NP 2x	6.0 kg/m ³ of natural phosphate	BAS 1x	6.0 kg/m ³ of Basacote
SPS 0.5x	1.06 kg/m ³ Super Phosphate Simple	BAS 2x	12.0 kg/m ³ of Basacote

Morphological parameters evaluated, like stem diameter and plant height, were measured each 30 days after germination (DAG), until 240 days. Evaluation of plant dry mass production and nutrient concentration in tissue were determined at 150 DAG in half of plants of each plot. This is the time when plant seedlings normally are transplanted to the field. Soil P availability was measured at 150 DAG, also. These data are not presented, but will be part of the presentation at the congress. The data were submitted to ANOVA analysis and significant means were compared by t test (LSD) at 5%, by the program SAS 8.2 (SAS Institute 2001).

Results and discussion

The results of plant height from germination to 240 days are presented in Figure 1. Evaluating for field conditions, it seems that slow solubility fertilizer has promoted better plant growth. The data in the Figure 1 indicate this, as plant height was higher for the treatments with Basacote. Soluble phosphate presented plant height a little bit lower than Basacote, but higher than witness. Statistically, Basacote and soluble phosphate promoted higher plant height 60 DAG, irrespective the rate used of these products. Natural phosphate promoted the worst results, showing plant P deficiency symptoms and lower growth than other treatments, being similar statistically to the witness.

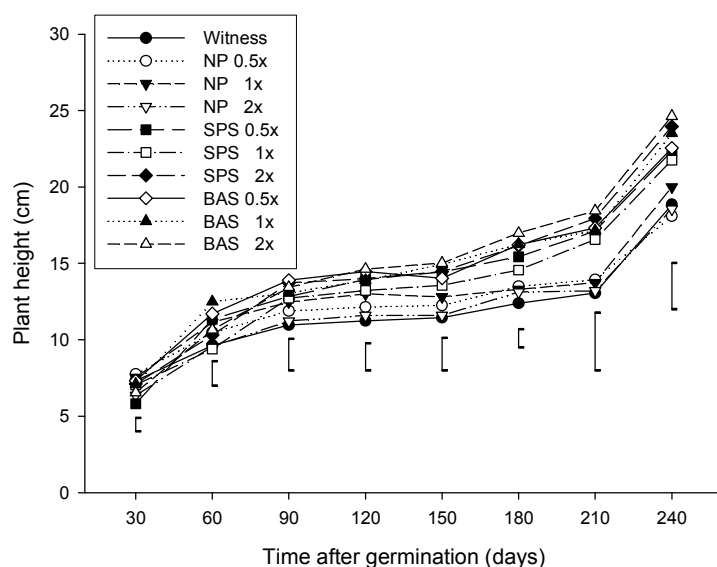


Figure 1. Pine seedling height, to 240 days after germination, for different rates and sources of phosphate fertilizers. UTFPR, Dois Vizinhas, PR, Brazil.

Stem diameter showed better development 60 DAG, being higher for Basacote and soluble phosphate treatments, increasing stem diameter as the rate increased (Figure 2). Development obtained by twice the recommended rate of Basacote (BAS 2x) increased substantially stem diameter 60 DAG when compared to

other treatments, in the field, the seedlings were more vigorous and stronger than for other treatments. Possibly, the use of slow solubility fertilizers, like Basacote, has promoted better development because nutrient solubilization occurs gradually, supplying plant demands exactly at the time it is necessary, promoting in this way, vigorous plant seedlings. Natural phosphate and witness presented similar results, as already observed for plant height.

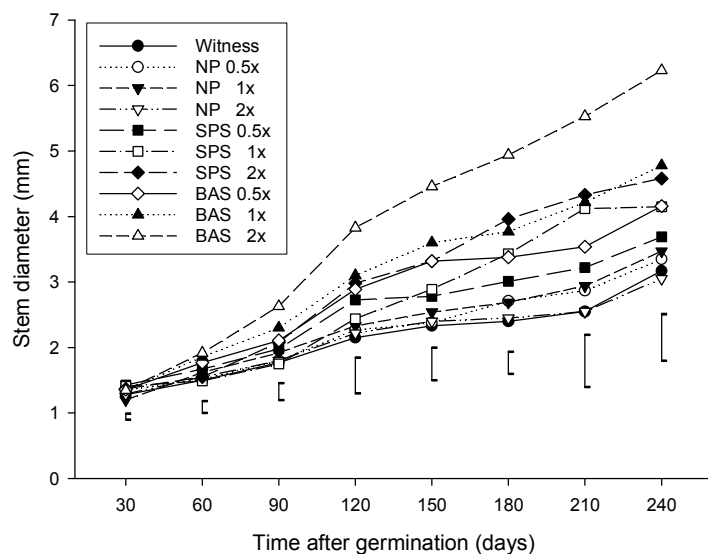


Figure 2. Stem diameter of pine plants, 240 days after germination, for different rates and sources of phosphate fertilizers. UTFPR, Dois Vizinhas, PR, Brazil.

Conclusion

Fertilization with slow solubility fertilizers, like Basacote, promoted better seedling growth, resulting in vigorous plants, with higher stem diameter and plant height after 240 days after germination. However, other morphologic parameters should be considered to produce seedlings with good nutritional conditions for future field adaptation and development.

References

- Guppy CN, Menzies NW, Moody PW, Blamey FPC (2005) Competitive sorption reactions between phosphorus and organic matter in soil: a review. *Australian Journal of Soil Research* **43**, 189-202.
- Novais RF, Smyth TJ (1999) 'Fósforo em solo e planta em condições tropicais'. (Viçosa: UFV)
- SAS Institute (2001) 'SAS user's guide: Statistics, Ver 8.2'. (Cary: NC).
- Tisdale SL, Nelson WL, Beaton JD (1985) 'Soil Fertility and Fertilizers'. 4th edition (Macmillan: New York)
- Vilela DT (2006) Pinus e micorriza: uma importante associação. Informativo ARESB. Ed. 82.
- WRB-FAO (1998) 'World Reference Base for Soil Resources'. (FAO: Rome).

Potato response to tillage and nitrogen management

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Abstract

Potato responses to different rates of pre-plant and in-season N management were evaluated under reduced and conventional tillage under center pivot irrigation. Tuber yield, tuber size distribution, and tuber specific gravity were largely similar across different tillage and N management practices. Potato was rotated with two years of sweet corn in this study. Frequency of in-season N application from 5 to 10 at a given N rate had no significant effects on tuber yield or quality. Reduced tillage offers savings in energy and labor costs, therefore, net return is expected to be greater under reduced tillage than that with conventional tillage despite similar yields and tuber quality under both treatments.

Key Words

Best management practice, fertigation, reduced tillage, nitrate leaching, tuber quality, pre-plant nitrogen, in-season nitrogen

Introduction

Total area under potato production in the U.S. Pacific Northwest (PNW, comprising Washington, Idaho, and Oregon) is 208,210 ha, with a total tuber production of 10.7 million tonnes; represents 55% of total U.S. production (National Potato Council 2006). Historically, 'Russet Burbank' has been the major cultivar in this region. A new cultivar, 'Ranger Russet' (large russet-skinned tubers that are well suited for baking and processing into french-fries), has gained increased adaption, in part, due to its greater resistance to *Verticillium* wilt, *Fusarium* dry rot, leafroll necrosis, and potato X and Y viruses than 'Russet Burbank' (Pavek *et al.* 1992).

The objective of this research was to evaluate different pre-plant and in-season N management practices on 'Ranger Russet' tuber yield and quality under center pivot irrigation with conventional (CT) vs. reduced tillage (RT).

Methods

This study was conducted on Quincy fine sand in Benton County, WA, under center pivot irrigation (Alva *et al.* 2009). Treatments included: I. two tillage: CT vs. RT; II: Four N-management rates and frequency: (kg/ha; as shown in Figure 3), with four replications. Pre-plant N rates (as per treatments) were applied as urea before planting. Phosphorus and potassium rates were applied based on soil test values. In-season N was applied as urea ammonium nitrate (UAN) solution (32% N).

Results and Discussion

Tillage effects were not significant on total tuber yield and tuber specific gravity across three years, as well as different size grade tubers during two out of three years (Figures 1 and 2). Total yield in 2004 as well as yield of large size tubers were than those in the next 2 years. Total tuber yield was not significantly influenced by different N management practices with total N rates in the range of 224 to 336 kg/ha and frequency of in-season N application 5 to 10 (Figure 3). In 2004, tuber yield was lower with 56 kg/ha pre-plant N as compared to that with 112 kg/ha. In summary, results of three years study support that RT had no negative impact on the tuber yield and/or tuber size distribution. Effects of long-term management of RT and CT on soil physical and biological properties are being investigated.

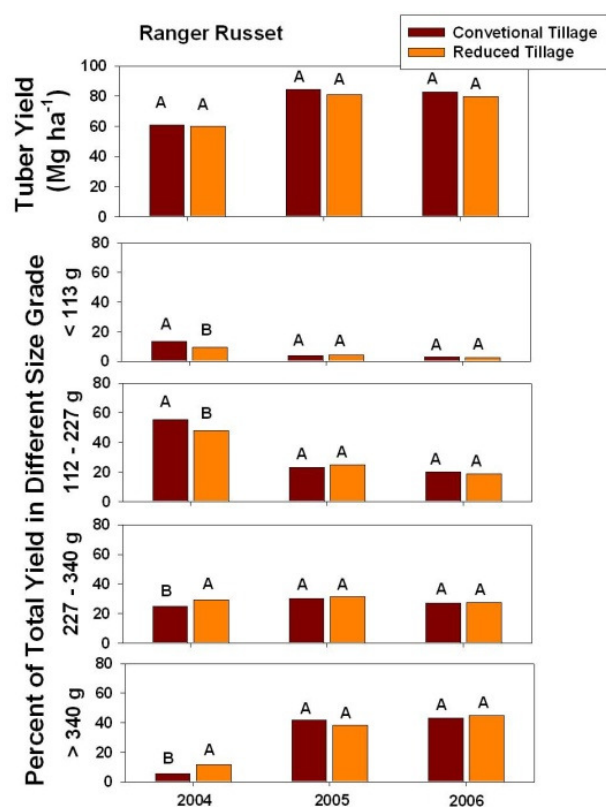


Figure 1. Total yield in size classes for 3 years for conventional and reduced tillage.

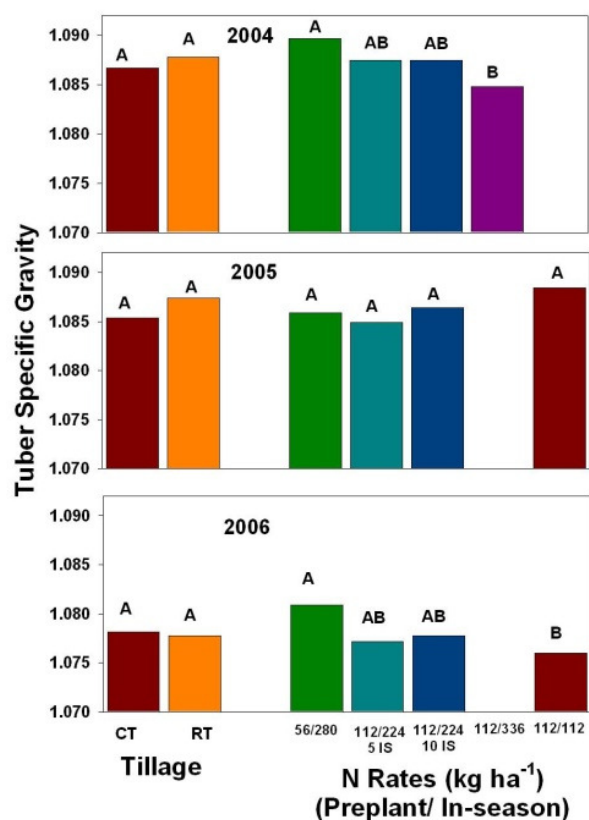


Figure 2. Tubes specific gravity over 3 years as affected by tillage and N rates.

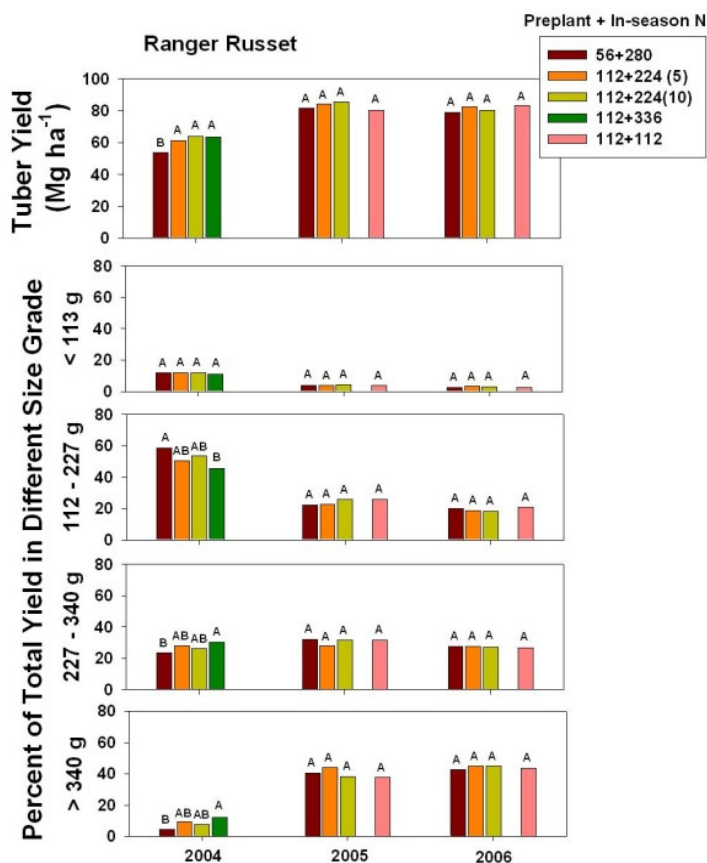


Figure 3. Percentage yield in size classes over 3 years in relation to N application method.

References

- Alva AK, Collins HP, Boydston RA (2009) Nitrogen management for irrigated potato production under conventional and reduced tillage.
- National Potato Council (2006) Potato Statistical Yearbook, 2006-2007. National Potato Council, Washington, D.C. pp.82.
- Pavek JJ, Corsini DL, Love S, Hane DC, Holm DG, Iritani WM, James SR, Martin MW, Mosely AR, Ojala JC, Stranger CE, Thornton, RE (1992) Ranger Russet: A long russet potato variety for processing and fresh market with improved quality, disease resistance, and yield. *American Potato Journal* **69**, 483-488.

Predictive value of resin extraction to determine sulfur and phosphorus response of maize in a range of soils from the New England Tablelands of NSW, Australia

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Abstract

An evaluation of the predictive capacity of resin sulfur (S) and phosphorus (P) extraction was undertaken on 18 soils from the New England Tablelands in northern NSW, Australia. Maize (*Zea mays*) plants were grown for 40 days in a glasshouse in the presence or absence of sulfur and/or phosphorus fertiliser, and relative yield was determined. Comparison of the relative yield response against resin extractable S, monocalcium phosphate (MCP) S and KCl40 S using a Cate-Nelson plot revealed little difference between the three S extraction methods when soil test values were below the identified critical levels. However, values above the critical value were better able to identify where fertiliser was not required in the resin and MCP tests. The inability of the KCl40 test to correctly identify when fertiliser would not be needed was related to the short time frame of the trial where the longer term reserves that it identifies are not able to be exploited by potted plants. Evaluation of P responses was not possible due to the responsiveness of all soils to applied P, despite critical values being above previously determined threshold values for more than one third of the soils examined. It remains unclear why all soils responded to P, however tissue P concentrations match with increasing response to soil P test values. In conclusion, there is no benefit in terms of predicting S response to move to a resin extraction method, and we were unable to determine if benefits would accrue with respect to P resin tests.

Key Words

Sulfur, phosphorus, fertiliser response, critical values, resin extraction.

Introduction

Efficient fertilizer application relies on the ability to predict when applications are likely to result in improved plant growth. Fertilizer application in the absence of plant response remains uneconomic and inefficient. Predicting response commonly relies on extracting soil and relating the soil test values to plant responses either in pot or field trials. Both monocalcium phosphate (MCP) and potassium chloride extraction at 40°C are used to extract soil sulfur (S) and critical values have been established (Blair *et al.* 1991). Similarly, in the New England region of NSW, Australia, Colwell (0.5M sodium bicarbonate) (Colwell 1963) and Bray (acidic ammonium fluoride) (Bray and Kurtz 1945) extractions have been used to predict P response. Earlier studies have concluded that roughly 80% of soils in the New England region are responsive to either S or P or both (Edwards and Duncan 2000) and the region is therefore ideal to compare existing tests against a resin extraction method to simultaneously measure plant available S and P. This paper reports on the comparison of a resin extraction method against standard methods to predict fertilizer response on 18 diverse soils from the New England.

Methods

Soil collection and preparation

Soil was collected from properties within a 100 km radius of Armidale in the New England region of NSW. Soils in this region are generally identified using 4 descriptors; granite soils (light textured soils with low water holding capacity and poor fertility), trap soils (texture contrast soils derived from sedimentary or meta-sedimentary parent materials), black basalt (heavy, smectite clay dominated soils) and red basalt (weathered paleosoils). Representative samples of each of these soils types were collected from the surface 10 cm of predominantly improved pastures, and screened to <1cm. One kg of each of the 4 soil types was placed in 13cm diameter pots and basal nutrients (150 mg N/kg, 50 mg K/kg, 20 mg Ca/kg, 20 mg Mg/kg, 2 mg Zn/kg, 2 mg Cu/kg, 0.2 mg B/kg and 0.2 mg Mo/kg) were applied. The S and P applications were applied as solutions of ammonium phosphate and ammonium sulfate. Sulfur was applied at a non-limiting rate of 20 mg S/kg. Phosphorus was applied at 100 mg P/kg for soils with phosphorus buffer indices (PBI) (Burkitt *et al.* 2002) <200; 200 mg P/kg for soils with PBI values between 200 and 400; and 400 mg P/kg for soils with PBI values above 400.

Plant and soil analysis

Maize (*Zea mays*) seeds were germinated and sown at 3 plants per pot, and maintained through regular watering to field capacity for 40 days. Glasshouse conditions were maintained between 18 and 28°C throughout growth. After 40 days, plants were harvested at the base of the stem, dried at 70°C for 48 hours, weighed, then ground to <2mm and digested using the sealed chamber digestion method (Anderson and Henderson 1986) and analysed for total nutrient concentrations using inductively coupled plasma atomic emission spectroscopy.

Soils were analysed for pH and EC, resin extractable P and S (Prochnow *et al.* 1998), MCP and KCl40 extractable S (Blair *et al.* 1991), Colwell (Colwell 1963) and Bray (Bray and Kurtz 1945) extractable P. A version of the Cate-Nelson statistical test was applied to the results and comparisons were made with each of the soil test extractions as related to relative yield in the absence of applied S or P.

Results

Sulfur soil extractions ranged from 3 to 18 mg S/kg in the resin, MCP and KCl40 extracts (Figure 1). Resin extractions were correlated with both MCP and KCl40 (Resin:MCP – $R^2=0.76$; Resin:KCl40 – $R^2=0.65$). Although MCP and KCl40 were not well correlated (MCP:KCl40 – $R^2=0.34$). In contrast resin P extractions ranged from 1 to 5 mg P/kg with the majority of values <3 mg P/kg, whilst Colwell ranged from 1 to 150 mg P/kg and Bray from 1 to 60 mg/kg. Correlations between extraction methods were only significant between Colwell and Bray ($R^2 = 0.58$).

Whilst 72% of the soils examined were S responsive (Figure 1), only 1 soil was not responsive to applied P fertilizer in this study (Figure 1). Hence it was not possible to use soil test values to effectively predict P response, as all soils were responsive to some extent.

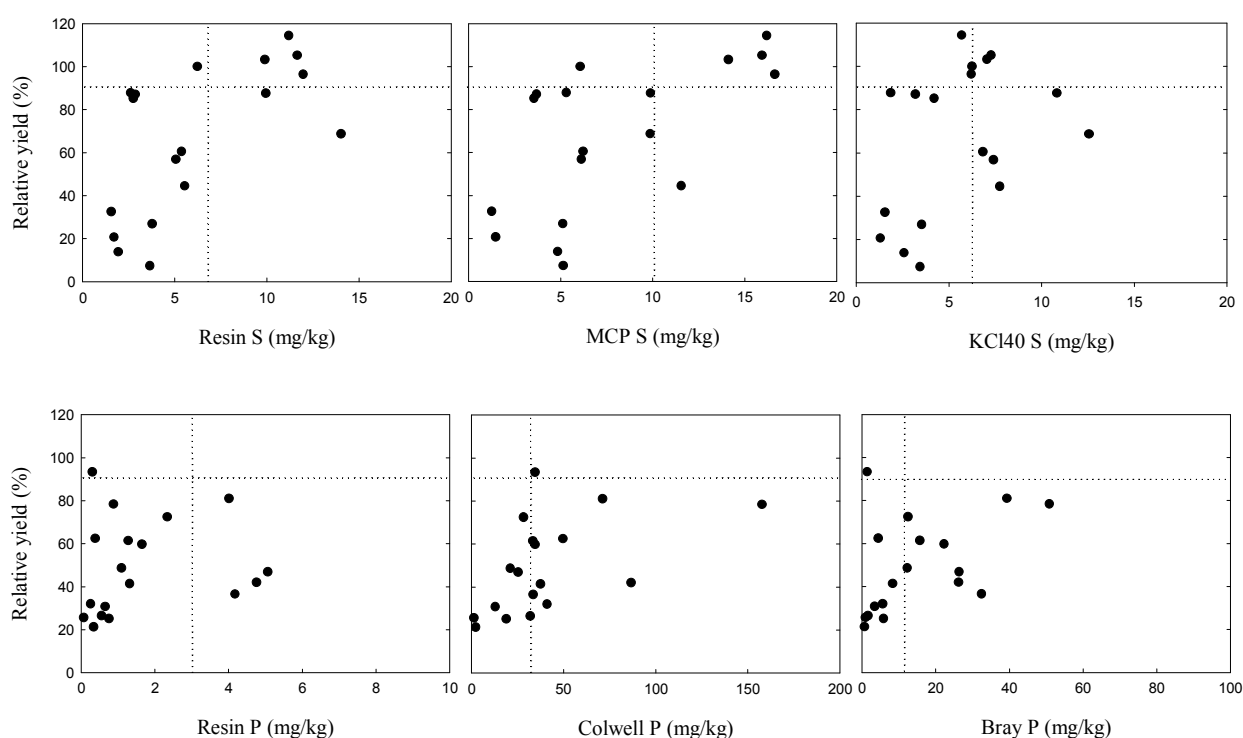


Figure 1 Relationship between soil test values and response of maize (*Zea mays*) plants to applied P or S fertilizer in 18 soils from the New England region of northern NSW, Australia. Known critical values were used to determine Cate-Nelson statistics for extractions other than resin extractions.

Critical S values were determined using Cate-Nelson plots and the predictive capacity of the critical values was compared using the proportion of false positive and false negative responses to fertilizer application (Table 1). There was no difference in the ability of the three soil S extractions to predict when soils would respond to applied S fertilizer (Table 1). However, more than half the soils predicted to be non-responsive according to the KCl40 extraction may have responded to fertilizer in this study.

Table 1. Critical values and predictive response to sulfur application as determined by Cate-Nelson plots for 18 soils from the New England region of northern NSW, Australia.

S test	Critical value (mg/kg)	% correct predictions when < critical value	% correct predictions when > critical value
Resin-S	7	92	67
MCP-S	10	92	80
KCL 40-S	6	89	44

Although soil P extracts were unable to detect significant differences in P response, tissue P concentrations linearly increased ($R^2 = 0.24$) in response to increasing available soil P reserves (Figure 2). A similar increase in tissue S concentration to increasing available S supply was also observed ($R^2 = 0.39$) (Figure 2).

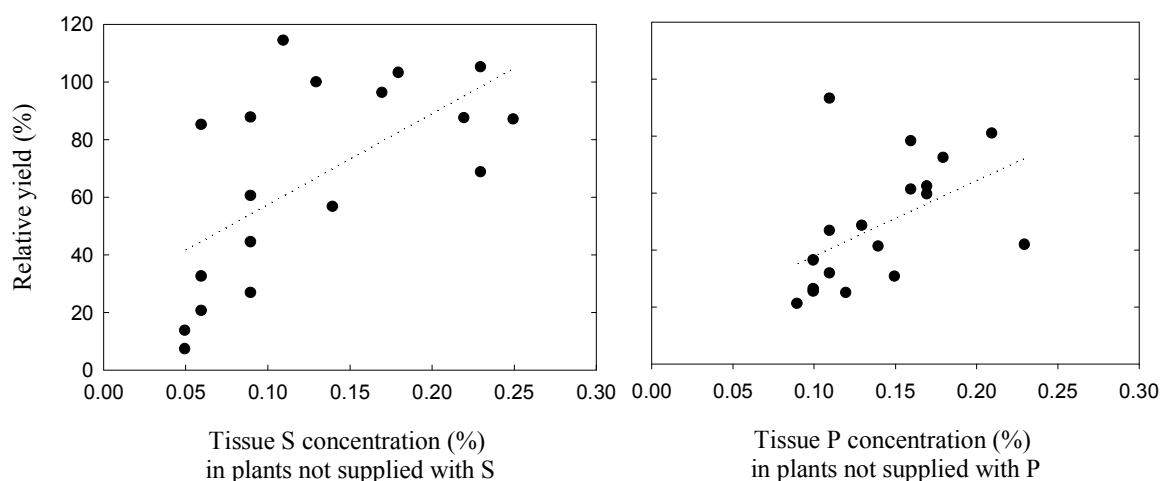


Figure 2. Tissue sulfur (S) and phosphorus (P) concentration in maize (*Zea mays*) plants in the absence of either P or S as related to the maximum yield grown in 18 diverse soils from the New England region of northern NSW, Australia.

Discussion

Extraction of soil S using resins did not significantly improve the predictive capacity to detect plant S responses over standard methods. Critical values determined for the MCP and KCl40 methods are in the range of those previously determined (Blair *et al.* 1991). This study therefore provides no support for changing standard soil S tests to the potentially more efficient P and S extraction using resins. The failure of the KCl40 test to accurately predict responsiveness above the critical soil test value in this study most likely relates to the short time frame of the study. KCl40 extractions typically sample a more representative fraction of available soil S, including that released through mineralisation of organic S compounds. Hence correlations are better over longer time frames. Over short incubation studies, it is often difficult to detect significant differences between methods that focus on inorganic S sources. Adequate tissue S concentrations for plants this age are $>0.20\%$ with one study citing a critical value for maize of 0.08% when grown in soil (Reuter and Robinson 1997). All plants in this study with less than 0.08% tissue S concentration were responsive to applied S.

It remains unclear why almost all soils examined in this study were responsive to applied P. In this study, more than one third of soils, according to soil test values and known predictive levels, were P unresponsive. Approximately 80% of soils in the New England were responsive to P in a study focussing on landholders who self-selected for soil nutrient advice. Explanations may involve i) conditions in the pot trial slowing the availability of native soil P; ii) conditions in the trial increasing the relative availability of applied fertiliser P; or; iii) interactions with other nutrients inducing P responsive conditions. Tissue concentrations for all other nutrients examined were in normal ranges, with no evidence of either toxic or deficient nutrient interactions likely, eliminating (iii), thus leaving either (i) or (ii) as potential options, or a combination of both. Adequate P concentrations are generally $>0.22\%$ tissue P for plants this age (Reuter and Robinson 1997), and all plants that were responsive to P and fell outside this range. This suggests that the release of P from native soil P pools was slower in this study than expected. No mechanism for this has yet been found.

Conclusion

Resin S and P extractions do not provide better predictive accuracy on soil S or P responsiveness in a wide range of New England soils.

Acknowledgement

This study was undertaken by students enrolled in SOIL411 and SOIL511 in the Bachelor of Rural Science degree or Master of Science in Agriculture Degree at the University of New England who gained valuable experience in applied research- H. Al-Azawi, S. Al-Masoudy, A. Abdullah, H. Baqir, R. Butler, P. Davis, A. Daweri, S. Gabb, L. Gleeson, C. Schonfeldt, S. Tshewang, I. Wermizyari

References

- Anderson DL, Henderson LJ (1986) Sealed chamber digestion for plant nutrient analysis. *Agronomy Journal* **78**, 937-938.
- Blair GJ, Chinoim N, Lefroy RDB, Anderson GC, Crocker GJ (1991) A soil sulphur test for pastures and crops. *Australian Journal of Soil Research* **29**, 619-626.
- Bray RH, Kurtz LT (1945) Determination of total, organic, and available forms of phosphorus in soils. *Soil Science* **59**, 39-45.
- Burkitt LL, Moody PW, Gourley CJP, Hannah MC (2002) A simple phosphorus buffering index for Australian soils. *Australian Journal of Soil Research* **40**, 497-513.
- Colwell JD (1963) The estimation of the phosphorus fertiliser requirements of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 190-197.
- Edwards C, Duncan M (2000) A review of 700 soil samples collected in the Armidale district between 1989-1999. In '15th Annual Conference of the Grassland Society' pp. 108-109.
- Prochnow LI, Pismel FS, Cantarella H, Vitti GC, Corrente JE, Kiehl JC (1998) Use of ion-exchange resin to evaluate the bioavailability of sulfur in the soil. *Communications in Soil Science and Plant Analysis* **29**, 1833-1841.
- Reuter DJ, Robinson BJ (1997) 'Plant Analysis: An Interpretation Manual.' (CSIRO: Collingwood).

Research on Nutrients Uptake and Accumulation in Grape vine

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Abstract

To find out the nutrient absorption, utilization and accumulation in grape vines, and to identify reasonable fertilizer rates and application periods, field experiments were conducted analyzing yearly biomass, nutrient contents and accumulation in different parts of grape vines (red globe) which were cultivated for about 7 years. The results show that total nitrogen absorption rate is 97.13 kg/ha in one year of the growing period. 39 % of that is absorbed during the new shoots flourishing period, and 30.5 % is uptaken during the fruit growing period. A total of 33.1 kg/ha potassium was absorbed in a year, about 3.1 kg/ha absorbed by leaves, and 11.9 kg/ha by fruits. Of 33.1 kg/ha phosphorus absorbed, 15.4 kg/ha was absorbed during the fruit growing period, being about 47 % of total uptake. A total of 140.52 kg/ha phosphorus was absorbed in a year, about 38.59 kg/ha absorbed during the new shoots flourishing period, and 64.29 kg/ha during the fruit growing period, representing 27.5% and 45.8% of the total uptake. The initial recommendation for N, P₂O₅, and K₂O applications required to offset nutrient removal within the orchard would be 129.5 kg/ha, 55.1 kg/ha and 175.6 kg/ha, respectively.

Key Words

Red globe grape vine, nitrogen, potassium, phosphorus, absorption, accumulation.

Introduction

Mineral nutrient elements such as nitrogen, phosphorus and potassium have important impact on the yield and quality of red-globe grape production in northwest China. The previous study has focused on this relationship, but little information is available on plant uptake, translocation, and distribution of N, P₂O₅, K₂O in grape vines. This article outlines a comprehensive study on the dynamics of N, P, K uptake and distribution within RED-GLOBE grape vines.

Methods

A trial was conducted in Fufeng County, on the Guanzhong of Shaanxi Province. The orchard was comprised of 7-year old red-globe grape vines with a row spacing of 1 m and 2.5 m between vines. The trial was carried out in 2006. Samples were taken from three vines at similar stages of development on six dates. Sampling took place on March 30 (sprouting and foliage growing period), May 10 (young fruit stage), June 30 (new shoots flourishing), August 20 (fruit expansion stage), September 30 (fruit maturity), and on November 30 (tree dormancy). Samples of fruit, foliage, new tops, branches, trunks, and roots were collected each time. Root samples included all those within a 100 cm depth and a radius of 50 cm around the trunk. The cortex and xylem within the trunks and roots were divided and analyzed separately. Enzymatic activity was destroyed by placing plant parts in an oven set at 100 to 105°C for 15 minutes, and then samples were dried to a constant weight at 70 to 80°C. Samples were ground and digested with concentrated sulfuric acid (H₂SO₄) and hydrogen peroxide (H₂O₂). The N content of the resulting solution was measured by flow injection analyzer, P content was measured colorimetrically, and K content was measured by flame photometer.

Equations

Nutrient accumulation(kg/ha)=nutrient content(g/kg)×organ biomass(kg per plant) ×plant per ha;

Nutrient absorption by new organs (leaves, new shoots, fruits) =nutrient accumulation calculated by the last sampling;

Nutrient absorption by old organs (branches, stem, roots) = nutrient accumulation calculated by the last sampling— nutrient accumulation calculated by the first sampling;

Total nutrient absorption= nutrient absorption by new organs+ nutrient absorption by old organs.

Results

The results of the study showed a sharp increase in biomass from the early growth period in May to fruit

maturity and harvest in September (Figure 1). Vine growth after this period slowed significantly, and biomass decreased because of defoliation and fruit picking. The biomass change of roots was not significant. In the main growing period, the biomass of roots fluctuated between 2303-4132 kg/ha, the net increase was 1830 kg/ha, about 14.8% of the gross.

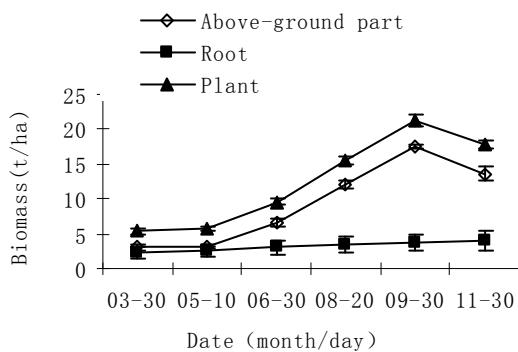


Figure 1. Annual changes of biomass

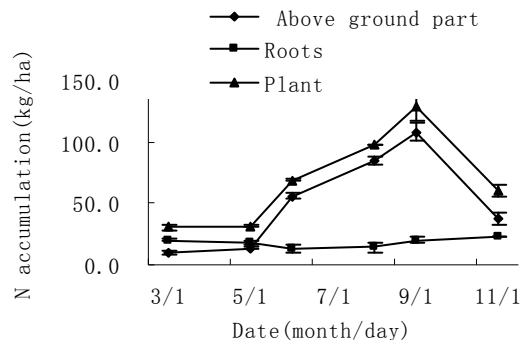


Figure 2. N accumulation in grape vine

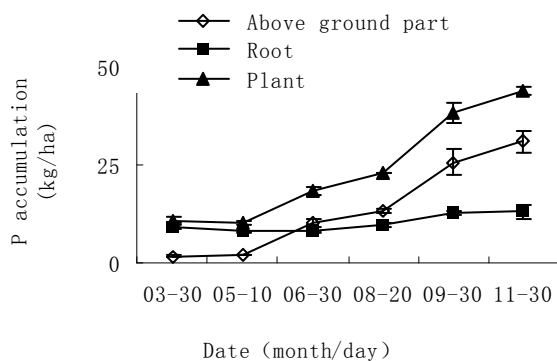


Figure 3. P accumulation in grape vine

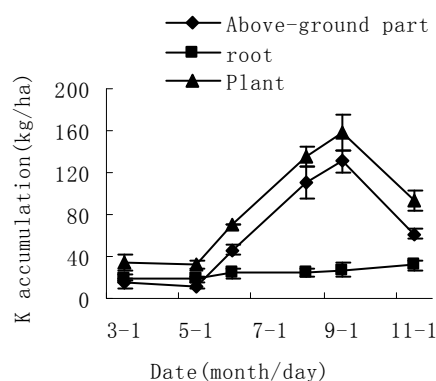


Figure 4. K accumulation in grape vine

Grape vines accumulated an average of 97.13 kg N/ha within the study period, in which N destined for fruit and foliage amounted to 32.72 kg N/ha and 35.09 kg N/ha, respectively (Figure 2). Vines absorbed the majority of N during the new shoots growth being about 39% of the gross. The days between August 20 and September 30 represented the peak period of demand for N. N accumulation after this period decreased significantly because of defoliation and fruit picking. Nitrogen loss should be replaced by fertilization.

A total of 33.1 kg/ha potassium was absorbed by grape vine in a year (Figure 3), in which 3.1 kg/ha absorbed by leaves, 11.9 kg/ha by fruits, and 3.8 kg/ha by roots. The days between August 20 and September 30 represented the peak period of demand for potassium, an average of 15.4 kg/ha potassium was accumulated during this period. Results also showed that grape vines mainly use reserved potassium to construct organs at an early stage, and potassium assignment is diverted along with the shift of growth center.

The total annual net phosphorus accumulation in this grape vine orchard amounted to 140.52 kg/ha (Figure 4), in which 17.24 kg/ha was absorbed by leaves, and 64.29 kg/ha by fruits. Among the new shoot growth period and the fruit growing period, grape vine demand more phosphorus, about 38.59 kg/ha accumulated during the new shoot growth period, and 64.29 kg/ha during the fruit growing period, 27.5% and 45.8% of the total uptake. Two distinct periods of plant K demand were identified, the first beginning in mid-May to June 30, and the second in mid-August to fruit harvest.

Table 1. Nutrient (kg) needed to attain 1000 kg economic yield for grape vine

Cultivars	Tree age	Nutrient needed to attain 1000 kg yield		
		N	P ₂ O ₅	K ₂ O
RED-GLOBE	7	4.05	1.84	7.8
Ju Feng	6	3.91	2.31	5.26
Cabernet Sauvignon	5	5.95	3.95	7.68

To attain 1000 kg economic yield, the grape vine should uptake nitrogen 4.05 kg, potassium 1.84 kg, phosphorus 7.8 kg (Table 1). This agrees with previous results, but is a little different because of tree age, cultivars, etc. Ju-Feng should uptake nitrogen 3.91 kg, potassium 2.31 kg, phosphorus 5.26 kg, and Cabernet Sauvignon need 5.95 kg, 3.95 kg and 7.68 kg, respectively.

Conclusion

It is difficult to quantify the fertilizer recommendation for grape orchards by soil testing and it is recommended to construct and monitor the nutrient balance in order to properly compensate for annual grape harvest and the amount of nutrient removed by fruits and leaves. Without considering nutrient supplied by soil, the initial recommendation for N, P₂O₅, and K₂O application required to offset its removal within the orchard would be 129.5 kg/ha, 55.1 kg/ha and 175.6 kg/ha, respectively. Results from this study indicate that approximately 39.4 kg N/ha should be applied basally in the autumn after fruit harvest and the remaining 50.7 kg N/ha and 39.4 kg N/ha should be applied prior to new shoots flourishing and fruit expansion, respectively. Approximately 29.2 kg P₂O₅/ha should be applied basally in the autumn after fruit harvest and the remaining 25.9 kg P₂O₅/ha should be applied prior to fruit expansion. Approximately 46.9 kg K₂O/ha should be applied basally in the autumn after fruit harvest and the remaining 48.3 and 80.4 kg K₂O/ha should be applied prior to new shoot growth and fruit expansion, respectively.

References

- ZHANG Zhi-yong, MA Wen-qi (2006) Studies on the Requirement and Accumulative Trend of Nutrients in Wine Grape 'Cabernet Sauvignon. *J. Acta Horticulturae Sinica* **33**(3), 466-470.
- The web of investigation and cooperation of grape (1993) Studies on nutrition characteristics and fertilization technique of grape. *Liaoning Agricultural Sciences* **5**, 4-8.

Response of *Pinus radiata* (D. Don) to boron fertilisation under greenhouse conditions

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Abstract

We studied the effect of different fertiliser boron (B) levels on growth, B uptake and photosynthesis of *Pinus radiata* and soil dehydrogenase activities under greenhouse conditions. Boron concentration in needle, stem and roots increased with increasing rates of B fertiliser. Boron at 4-8 kg/ha increased growth and net photosynthetic rate. However, higher rates reduced net photosynthetic rate and diameter growth. Soil dehydrogenase activity, an indicator of soil microbiological activities, was significantly reduced by B application at the rate of 16 and 32 kg/ha. Our findings confirm the narrow range between B deficiency and toxicity in a tree crop.

Key Words

Pine, B nutrition, soil microbial activity.

Introduction

Pinus radiata is the dominant plantation forestry species planted on over 1.8 million hectares of New Zealand's total geographical area of 26.9 million hectares. The New Zealand forest industry contributes 1.1% of the global and 8.8% of the Asia-Pacific forest product trade (NZFIC 2005). With respect to New Zealand's economy, the forestry sector contributed 3.2 % to total export earnings during 2003/2004; the major share of this earning attributed to *P. radiata* plantation (NZFIC 2005). Boron (B) deficiency is the most common micronutrient limitation in conifer forests (Shorrocks 1997). In *P. radiata*, B deficiency can cause the death of terminal buds, arrest the growth of leader shoots and lead to permanent stem malformation, which will reduce both wood volume and quality (Olykan *et al.* 1995). In New Zealand, B deficiency often occurs in coarse textured soils such as the pumice soils of the Central North Island and the Moutere gravels near Nelson in the South Island. The correction of B deficiency in *P. radiata* plantations involves the use of slow-release B fertiliser. However, very little information is available on the effect of different rates of slow-release B fertiliser on plant growth and physiological properties and soil microbiological activities.

Material and method

Trial design and plant growth condition

A pot trial was conducted at Palmerston North, New Zealand under greenhouse conditions by applying five levels of B in the form of ulexite (rate equivalent to 0, 4, 8, 16 and 32 kg B/ha) to one year old radiata pine grown in 6 L plastic pots containing a Pumice Soil collected from the Taupo region. Each treatment was replicated five times and arranged in a randomised complete block design. The glasshouse temperature was maintained at 17.5 ± 1 °C (night) and 22.5 ± 1 °C (day). Pots were irrigated regularly to maintain soil moisture at 80 % of field capacity.

Measurement and chemical analysis

Tree height and stem diameter were measured every two weeks and at harvest stage. Net photosynthesis was measured before harvesting by using a CIRUS-2 Portable Photosynthesis system. Plant B concentration was determined for each harvested organ (needle, shoot) by dry ashing followed by measuring the B in the ashed extract colorimetrically by the azomethine-H method (Gaines and Mitchell 1979). Soil dehydrogenase activity after harvest was determined through incubation of soil sub-samples at 37 °C for 24 h (Chander and Brookes 1991). Plant-available soil B was extracted using 0.02 M hot CaCl₂ method (Parker and Gardner 1981). The concentration of B in the extracts was determined using colorimetric analysis by the azomethine-H method (Gaines and Mitchell 1979).

Results and discussion

Plant growth

Different responses to B fertiliser rates were observed for plant height and stem diameter (Figure 1 a, b). Maximum plant height (47.13 cm) was obtained with B application at the rate of 8 kg/ha. Plant height appeared to be lower at 16 and 32 kg/ha than at 8 kg/ha, although there was no significant difference. Maximum stem diameter was obtained with B application at the rate of 4 kg/ha. Higher rates of B fertiliser reduced stem diameter growth. However, measured values were greater relative to the control (0 kg B/ha). These results were generally in agreement with the field observations of Olykan *et al.* (2008).

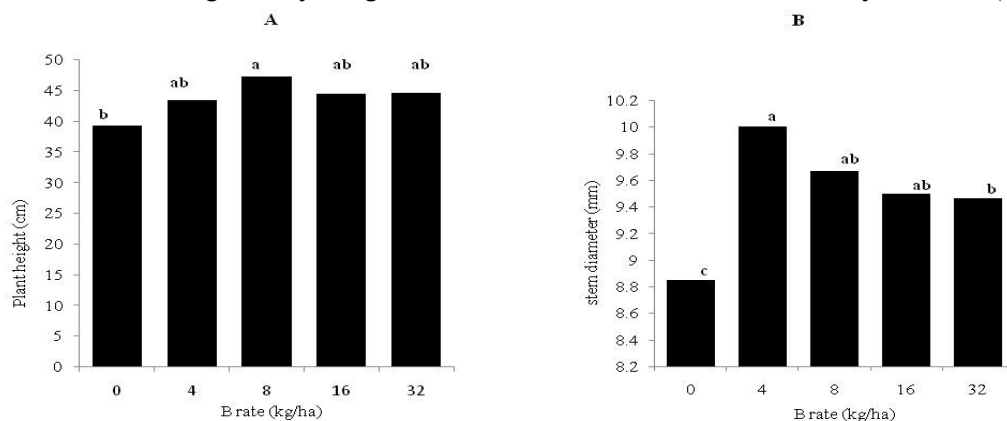


Figure 1. Effect of different B rates on A. Plant height and B. Stem diameter.

Net photosynthesis rate and soil dehydrogenase activity

Needle net photosynthetic rate (Np) was significantly lower at B rates of 0, 16 and 32 (Figure 2 a) relative to 4 and 8 kg/ha. The greater Np at B rates of 4 and 8 kg/ha could be responsible for the better growth of the trees observed for these two treatments. Both B deficiency and toxicity have been reported to influence photosynthesis (Dell and Huang 1997, Lee and Aronoff 1966). Soil dehydrogenase activity, an index of soil microbial metabolic activity, was significantly reduced at the B rates greater than 8 kg/ha (Figure 2 b). This implies that high rates of B fertiliser could be toxic to some soil microorganisms sensitive to added chemicals.

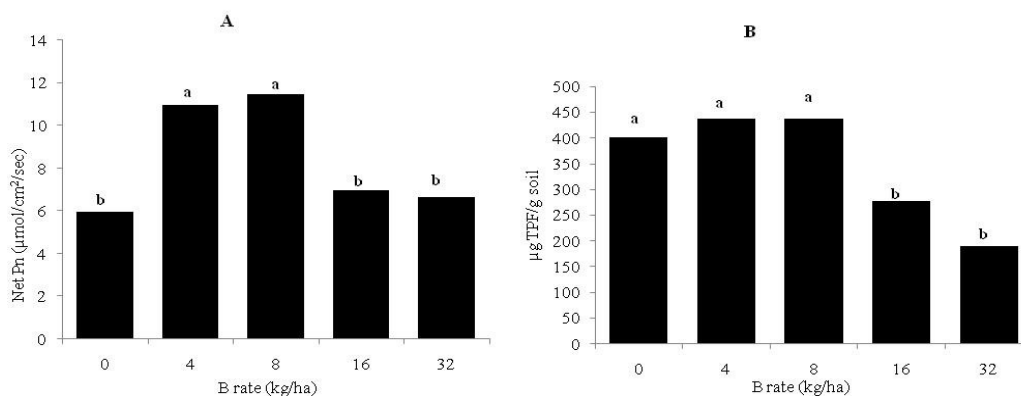


Figure 2. Effect of different B rates on A. Net photosynthesis and B. Soil dehydrogenase activities.

Needle and soil B concentrations

Across all ages of harvested needles (i.e. mature and immature needles) B concentrations significantly increased with increasing rates of B fertiliser (Figure 3). A greater increase in needle B concentration was found at B rates up to 16 kg/ha with little or no effect of further B fertilisation. The B concentration in currently mature needles for the control treatment was 12 mg/kg. This is approximate to the marginal level defined by Will (1985) and less than the 16-70 mg/kg range reported to be adequate for B in young mature foliage of *P. radiata* by Reuter and Robinson (1997). The needle B concentrations at the rates of 16 and 32 kg/ha were all greater than 170 mg/kg, which is reported to be the toxic threshold value for radiata pine growth (Reuter and Robinson 1997). Toxicity of foliar B at high fertilisation rate may explain the observed declining plant growth and photosynthetic capacity. The concentration of CaCl_2 extractable soil B also increased with increasing rates of B fertiliser (Figure 4 a). The much greater availability of soil B at 32 kg/ha may have caused a toxic accumulation of B in the needles at this treatment.

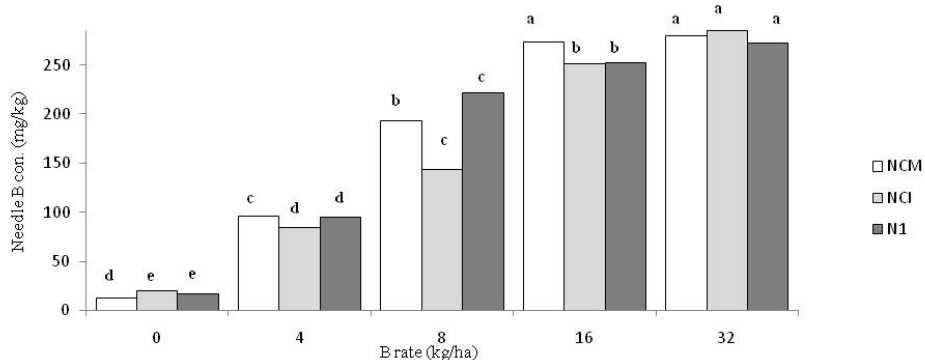


Figure 3. Effect of B rates on B concentration (mg/kg) in different age-group N1(1-year old), NC1 (currently immature) and NCM (currently mature) needles.

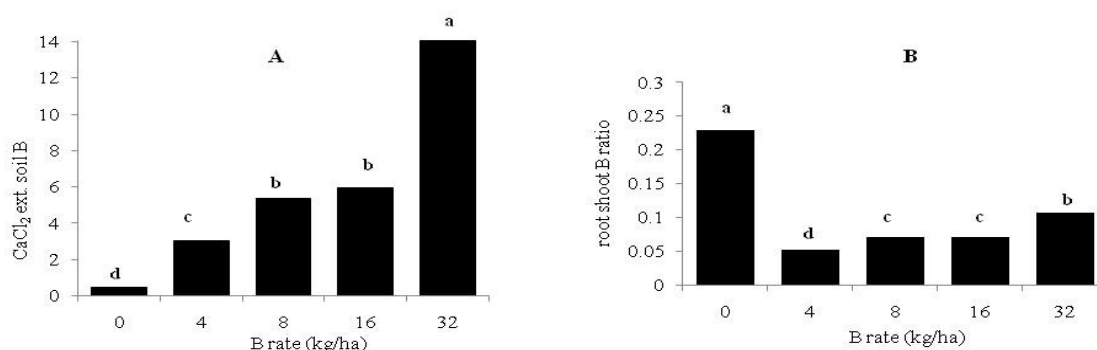


Figure 4. Effect of different B rates on A. CaCl₂ extracted soil Boron and B. Root : shoot B ratio.

Root /needle B ratio (RNR)

Greater RNR was found in the control (no B) and highest B rate (32 kg/ha) when compared with the optimum B application rates (Figure 4 b). Analysis of the B distribution among different plant parts indicated that translocation of B from root to the above-ground parts (e.g. needles) could be restricted under stress conditions caused by both low and high B levels. Our results agree with earlier reports where low translocation of B from roots to shoots promoted vascular impairment through B deficiency (Dell and Huang 1997). Our data suggests a similar response through B toxicity.

Conclusions

In this study we assessed the effect of increasing soil B levels on growth of *P. radiata*. Boron was found to increase plant height, diameter and dry weight up to an optimal level of soil B (3-6 mg/kg CaCl₂ extractable B). However, B in excess of the optimal concentration affected a decrease in photosynthetic activity. No level of application promoted an increase in soil microbiological activity. High application of B was found to be toxic to soil microorganisms.

References

- Chander K, Brookes PC (1991) Is the dehydrogenase assay invalid as a method to estimate microbial activity in copper-contaminated soils? *Soil Biol. Biochem* **23**, 909-915
- Dell B, Huang L (1997) Physiological response of plants to low boron. *Plant and soil* **193**, 103-120.
- Gaines TP, Mitchell GA (1979) Boron determination in plant tissues by the azomethine-H method. *Comm. soil sci. Plant Anal.* **10**, 1099-1108.
- Lee SG, Aronoff S (1966) Investigation on the role of boron in plants. III anatomical observations. *Plant physiol* **41**, 1570-1577.
- New Zealand Forest Industries Council (NZFIC) Fact and Figures 2004/2005, 85 The Terrace PO Box 2727, Wellington Website: www.nzfic.org.nz
- Olykan ST, Adam JA, Nordmeyer AH, McLareen RG (1995) Micronutrients and macronutrients uptake by *P. radiata*, and boron fractions, as affected by added nitrogen and boron. *N.Z. J. For. Sci.* **25**, 61-72.
- Olykan ST, Xue J, Clinton PW, Skinner MF, Graham DJ, Leckie AC (2008) Effect of boron fertiliser, weed

- control and genotype on foliar nutrients and tree growth of juvenile *P. radiata* at two contrasting sites in New Zealand. *For. Ecol. Manage.* **255**, 1196-1209.
- Parker D, Gardner EH (1981) The determination of hot-water soluble boron in some acid Oregon soils using a modified azomethine-H procedure. *Comm soil sci. Plant Anal.* **12**, 1311-1322.
- Reuter DJ, Robinson JB (1997) Plant Analysis - an interpretation manual Eds. CSIRO Publishing.
- Shorrocks VM (1997) The occurrence and correction of boron deficiency. *Plant and Soil* **193**, 121-1489.
- Will GM (1985) Nutrient deficiency and fertiliser use in New Zealand exotic forests. *N.Z. For. Res. Inst. Bull.* **97**, 53 pp.

Rice yield affected by gypsum, lime and silicate application in no tillage system

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Abstract

The objective of this work was to evaluate the effects of combined silicate, lime and gypsum on acidity correction of the soil profile and on rice development. The experiment was carried out in Selvíria-MS, Brazil, at the College of Engineering, UNESP – Ilha Solteira-SP. The experimental design was the completely randomized block, with eight treatments and four replications. Treatments consisted of: control, gypsum, lime, silicate, lime+silicate, lime+gypsum, silicate+gypsum and lime+silicate+gypsum. Before and 12 months after the application, pH, H+Al, exchangeable Ca, Mg and K, SO₄²⁻ and extractable Si levels in soil were determined. Yield components and rice yields were measured. Some soil chemical attributes (pH, Ca, Mg, K, V%) were affected by the materials for acidity correction both applied separately and mixed. The number of panicles was increased by the superficial application of gypsum mixed with other materials, consequently affecting rice yield.

Key Words

Acidity correction, soil chemistry, *Oryza sativa*.

Introduction

The concept of no tillage system supports sowing without any kind of soil disturbance, including other aspects such as crop rotation with high dry matter production and the appropriate management of soil physical and chemical attributes. Soil fertility and acidity correction down the profile plays an important role in successfully establishing and consolidating no tillage system for many years. Soil acidity limits crop production in most areas under no tillage systems. Soil correction has been carried out with superficial liming, only leveling the material or with no incorporation at all. However, lime reactivity is usually restricted to the area where it was applied or incorporated. This material has low mobility and thus its use is questionable. Replacing part of the lime with other correction materials, such as some Ca and Mg silicates, may be a feasible option, since these are seven times more soluble than carbonates. Gypsum may also be used to enhance soil profile for better root growth. Therefore, some alternatives for acidity correction of the soil profile with no incorporation may contribute to make no tillage system viable. The objective of this work was to evaluate the effects of superficial application of combined silicate, lime and gypsum on acidity correction of the soil profile, rice nutrition, yield components and grain yield in no tillage system.

Methods

The experiment was carried out in Selvíria-MS, Brazil, at the College of Engineering, UNESP – Ilha Solteira-SP (51° 22' W, 20° 22' S, 335 m asl), in 2003/04 and 2004/05. Rice and bean were cropped in summer and winter, respectively, as crop rotation. Soil was a clayey Oxisol. Before the experiment, samples were taken for chemical analysis to estimate lime and gypsum necessity and to improve the area (Table 1). The experimental design was the completely randomized block, with eight treatments and four replications. Plots were 35 m² (5.0m x 7.0m). Treatments were: 1 – Control (no gypsum nor other materials), 2 – Gypsum (only gypsum application), 3 – Lime (only lime application), 4 – Silicate (only silicate application), 5 – Lime + Silicate (lime combined with silicate - LS, half dose of each), 6 – Lime + Gypsum (total dose of lime combined with the total dose of gypsum - LG), 7 – Silicate + Gypsum (total dose of silicate combined with the total dose of gypsum - SG) and 8 – Lime + Silicate + Gypsum (lime combined with silicate, half dose of each – and total dose of gypsum - LSG).

Doses for lime (2.1 t/ha) and silicate (2.2 t/ha) (Agrosilício[®], Recmix Company) application were calculated to reach 70% of base saturation. Gypsum dose (3.0 t/ha) was calculated according to clay content in soil (500 g/kg). The products were combined using a cement mixer. Then, the materials were applied manually on soil surface, with no incorporation and just in the first year of the experiment, before rice sowing. The experiments were carried out under center pivot irrigation. Tensiometers were used for monitoring and to

Table 1. Soil chemical attributes before the experiment.

Depth (cm)	pH (CaCl ₂)	O.M. g/dm ³	P (resin) (-----mg/dm ³ -----)	S-SO ₄ ²⁻ (-----mmol/dm ³ -----)	Si ^A	Al	H+Al	K	Ca	Mg	CEC	V %
0-20	5.1	27	20	16	5.9	0.0	40	1.5	19	12	72.5	45
0-5	5.1	28	22	14	6.2	0.0	40	3.3	18	14	75.3	47
5-10	5.1	25	28	14	5.4	0.0	40	0.7	16	10	66.7	40
10-20	5.2	26	16	16	5.7	0.0	37	0.6	18	13	68.9	46
20-40	5.3	23	8	40	4.7	0.0	34	0.6	12	9	55.6	39

^Acalcium chloride extractant

indicate need for water application, maintaining 0.058 MPa (vegetative and maturation stage) and 0.033 MPa (reproductive stage). Upland rice cultivar Primavera was sown in a 0.36 m row spacing. Density was 80 viable seeds per meter. Each plot consisted of 12 rows with 7 m length. The 4 central rows were the useful area, except 0.5 m in the extremity of each. Fertilization in both growing seasons consisted of 200 kg/ha of the NPK formula 08-28-16 + 0,4% of Zn applied in the furrows, and 60 kg/ha of urea for N supply. Samples were taken 12 months after the application of the materials in the depths 0-0.05, 0.05-0.10, 0.10-0.20 and 0.20-0.40 m. At random, eight simple samples per plot from each depth were taken to form a composite sample. These were dried, sieved (2 mm) and submitted to chemical analysis of pH (CaCl₂ 0.01 mol/L), potential acidity (H+Al), exchangeable Ca, Mg and K, and base saturation (V%), according to Raij *et al.* (2001). SO₄²⁻ levels were determined through calcium phosphate extraction. Si levels were evaluated according to Korndörfer *et al.* (1999). Yield components (number of panicles per m², total number of spikelets per panicle, spikelet fertility, weight of 1000 grains) and rice yield were also determined. Data was submitted to variance analysis and means were compared by the Tukey test at a probability level of 10%.

Results

Superficial application of lime, silicate and gypsum influenced the number of panicles per m² (Figure 1). The number of panicles per m² was higher than the control for silicate mixed with gypsum. Nevertheless, it did not differ from the others that were mixed with silicate, inferring the effects of Si on the number of panicles per m². The role of Si in the number of panicles per m² is not well described. According to Ma *et al.* (1989), Si hardly affected the vegetative stage. The other yield components did not differ statistically. Means were 183, 81% and 23,8 g for spikelets per panicle, spikelet fertility and weight of 1000 grains, respectively. Grain yield (Figure 1) was significantly increased by the materials and mixtures (LS, LG, SG and LSG) compared to the control. The treatment SG showed the higher yield (4,362 kg/ha). Either the combinations LS and LSG or each product applied separately showed similar effects.

According to Figure 2, pH was affected by the treatments only down to 0-0.05 m. In general, there were no effects either for the products applied separately (lime and silicate) or mixed (Figure 2). Therefore, although silicate is more soluble than lime, it was not more effective in neutralizing soil acidity in deeper layers. Gypsum application increased S-SO₄²⁻ levels down the whole profile, although higher accumulation was found in the depths 0.10-0.20 and 0.20-0.40 m, corroborating the results observed by Caires *et al.* (2003) and Soratto and Crusciol (2008). Lime and silicate, applied either separately or mixed, also increased sulphate levels in deeper layers, reaching higher values in the depth 0.20-0.40 m. K levels were decreased significantly by the treatments in the depths 0-0.05 m and 0.20-0.40 m. The application of lime and

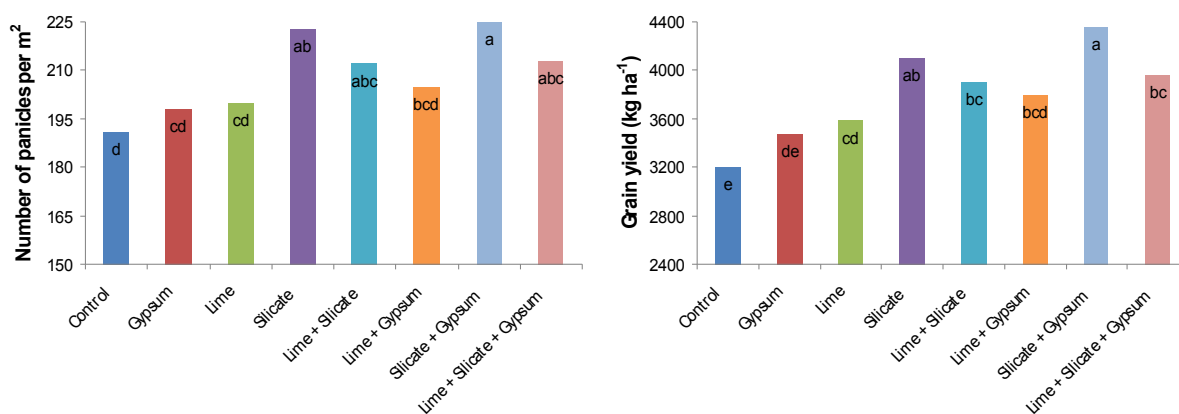


Figure 1. Number of panicles per m² and rice yield as affected by materials for acidity correction and gypsum under no tillage system. Average of 2003/04 and 2004/05.

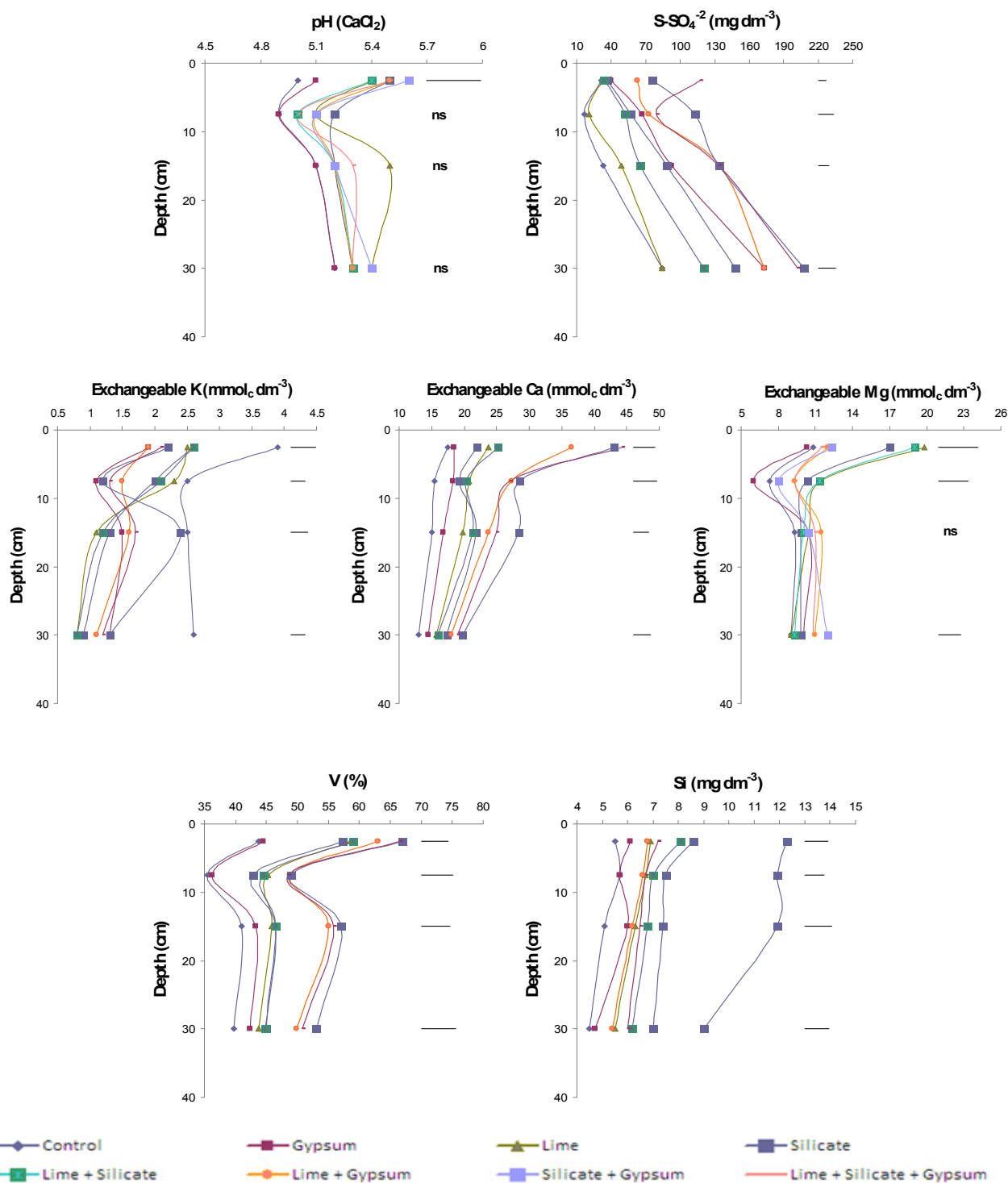


Figure 2. pH, H+Al, S-SO₄²⁻, exchangeable K, Ca and Mg, base saturation (V%) and Si levels in soil as affected by materials for acidity correction and gypsum under no tillage system 12 months after superficial application.

silicate+gypsum, in the depths 0.05-0.10 and 0.10-0.20 m respectively, were similar to the control. The influence of materials for acidity correction on K leaching is clearly explained by the decrease in K levels compared to the control. Leaching can be a result of SO₄²⁻ and NO₃⁻ working as accompanying ions. Also, there is the influence of mass in K mobility, due to Ca and Mg added by the products, which compete for the same sorption sites.

Whenever gypsum was added to any of the other products, higher Ca levels were found in all depths (Figure 2). Lime and silicate applied either separately or mixed (LS) showed intermediary values, between the results with gypsum separately or mixed to other materials and the control. Silicate + gypsum greatly influenced Ca levels due to a higher solubility of both products compared to lime. Ca leaching probably occurred due to

SO_4^{2-} and NO_3^- leaching, since both can be accompanying ions for this cation. Considerable mobility of Mg to deeper layers was observed whenever gypsum was mixed with other products, mainly silicate. The application of the materials for correction either separately or mixed (LS) resulted in lower Mg leaching and thus higher levels of this nutrient were found in upper layers (0-0.05 m and 0.05-0.10 m). Base saturation (Figure 2) was influenced indirectly by the treatments due to higher levels of K, Ca and Mg, i.e., the products affected V% in all depths mainly because of Ca and Mg increase. Higher levels were found in the upper layer (0-0.05 m); however, the aimed base saturation was not reached (70%). Better results in all depths were obtained whenever gypsum was added to the other materials. This is a promising alternative for soil acidity correction down the profile in no tillage system with no incorporation. Silicate applied separately (23% of SiO_2) increased Si levels in all depths. Similar results were observed for liming.

Conclusion

Superficial application of silicate in a no tillage system was no better than lime in neutralizing soil acidity down the profile, showing similar efficiency. Some soil chemical attributes (pH, Ca, Mg, K, V%) were affected by the materials used for acidity correction both applied separately and mixed. The number of panicles per m^2 and, consequently, rice yield, were affected by the superficial application of gypsum mixed with other materials for acidity correction.

References

- Caires EF, Blum J, Barth G, Garbuió FJ, Kusman MT (2003) Alterações químicas do solo e resposta da soja ao calcário e gesso aplicados na implantação do sistema de plantio direto. *Revista Brasileira de Ciência do Solo* **27**, 275-286.
- Korndörfer GH, Coelho NM, Snyder GH, Myzutani CT (1999) Avaliação de métodos de extração de silício em solos cultivados com arroz de sequeiro. *Revista Brasileira de Ciência do Solo* **23**, 101-106.
- Ma J, Nishimura K, Takahashi E (1989) Effect of silicon on the growth of rice plant at different growth stages. *Soil Science Plant Nutrition* **35**, 347-356.
- Raij BV, Andrade JC, Cantarella H, Quaggio JA (2001) 'Análise química para avaliação da fertilidade de solos tropicais'. (Campinas: Instituto Agrônomo).
- Soratto RP, Crusciol CAC (2008) Atributos químicos do solo decorrentes da aplicação em superfície de calcário e gesso em sistema plantio direto recém-implantado. *Revista Brasileira de Ciência do Solo* **32**, 675-688.

Risk for N losses after harvest in tilled and untilled clays

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Abstract

There have been indications that the increase of mineral N and increased risk of leaching that has been observed in light textured soils after early tillage in autumn should be as pronounced in heavier textured soils. The results of this study in 24 soils ranging from loam to clay indicate that mineralisation is similar independent of texture and that the risk for losses is similar. However, leaching could be a smaller problem in clays and the main mechanism for losses would instead be denitrification.

Key Words

Nitrogen losses, nitrogen mineralization, soil texture, soil porosity, clay soil.

Introduction

Previous research has clearly shown that the risk of nitrogen (N) leaching on light-textured soils is related to the timing of autumn tillage. Early autumn tillage stimulates N mineralization and increases the mineral N content of soil under moist and relatively warm conditions (Adu and Oades 1978; Hassink 1994) that are normal for the autumn in Sweden. Since water fluxes in the soil are normally highest in autumn and winter, the risk of leaching therefore increases. On clay soils, existing data are more contradictory and there is often no increase in the amount of mineral N in the soil profile as a result of early tillage (Stenberg *et al.* 2005). Considering the possibility for weed management and the reduced risk of soil compaction with early tillage compared with later autumn tillage, there are advantages in not delaying autumn ploughing unnecessarily. The amount of N mineralized as a result of tillage is dependent on the amount of mineralizable N present, and thus the soil humus content can be expected to be a significant factor, as can the clay content, since clay both retains moisture and physically protects the humus from decomposition. This protection can be destroyed when the soil is cultivated and aggregates are broken up along partly new fracture surfaces.

In this project, we investigated how soil parameters affected accumulation of mineral N in the soil after early ploughing at the beginning of September compared with a control soil (not ploughed until November).

Methods

Twelve sites where pig manure was used in the crop rotation and 12 sites without manure were selected to span a range of soil textures from loam to clay and a range of humus contents. All 24 sites were located within a radius of ca: 15 km centred 100 km NW of Gothenburg, Sweden. The soil parameters measured were soil texture and humus content down to 90 cm depth, porosity, pore size distribution, and fresh and dry bulk density in the topsoil, the plough pan and the central subsoil. On the topsoil samples, NIR determinations and analyses were also carried out for determination of potential N mineralization. The amount of ammonium and nitrate in the 0-30, 30-60 and 60-90 cm soil layers was determined immediately before ploughing in both the early ploughed and late ploughed plots. The experiment was conducted in the autumns 2002-2004. The differences between treatments, years and depths in amount of nitrate, ammonium and total mineral nitrogen were visualised by box-whisker plots.

Results

Summer was somewhat wetter than normal in all three years but August and September (i.e. just before and after early tillage) were drier than normal in 2002 and 2003 (Figure 1). Rainfall was normal in autumn 2004. The clay content at the sites varied between 19 and 54 % in the topsoil (mean = 37 %) and up to 64 % in the subsoil. Humus content varied between 2.8 and 11.5 % in the topsoil but was only above 5% at two sites (mean = 4.2%).

No differences in mineral N could be found between manured and unmanured soils. The amount of mineral N in the soil profile in the drier autumns of 2002 and 2003 differed greatly from that in the normal rainfall autumn of 2004 (Figure 2). In September 2002 and 2003, the amount of mineral N down to 90 cm depth was on average 30 kg/ha in both treatments (range 12-74 and 12-97 kg N/ha respectively). By November, the

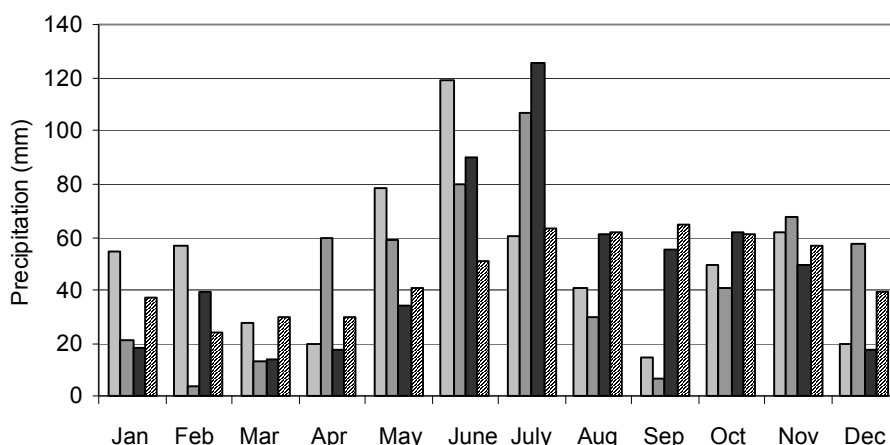


Figure 1. Monthly precipitation the three experimental years 2002-2004 and the 30 year average (dashed).

mineral N content had increased by an average of 10 kg/ha in the late-ploughed control and 30 kg/ha in the ploughed treatment. Thus early ploughing resulted in a 20 kg/ha higher accumulation of mineral N during the autumn. However, the variation in difference between the ploughed treatment and the late-ploughed control was large (-30-67 kg N/ha in 2002 and -8-57 kg N/ha in 2003) and this difference could not be explained by any of the soil parameters measured, apart from the fact that it was greatest at the two sites with the highest humus content.

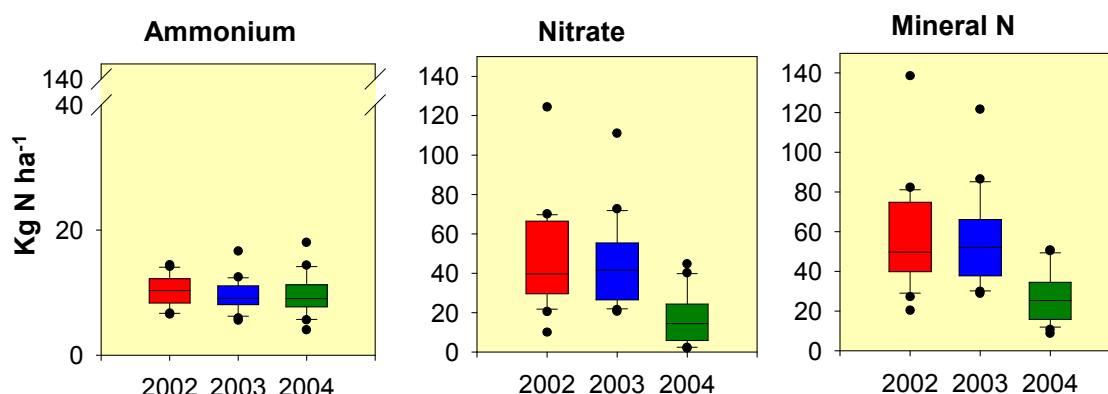


Figure 2. Box-whiskers plots over the amount of ammonium, nitrate and total mineral N (0-90 cm) at the 24 sites in November in the early tilled treatment. The line indicates the median, the box the 25th/75th percentile, the whiskers the 10th/90th percentile and dots individual outliers.

In 2004, no clear increase in mineral N between September and November could be observed. The levels of mineral N were also much lower in the top soil compared to 2002 and 2003. The difference was small in the sub soil (Figure 3). It was mainly the nitrate content that was smaller in 2004.

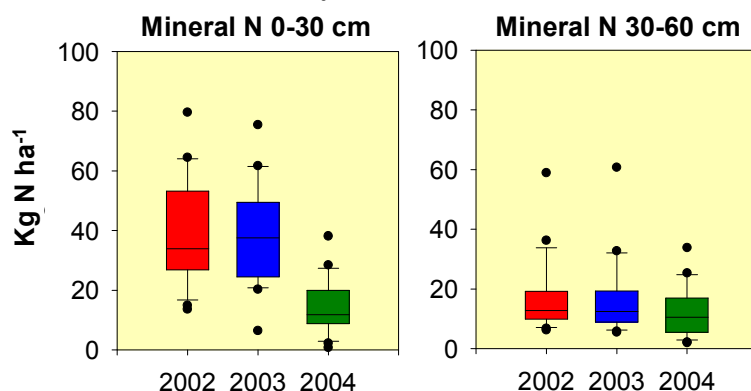


Figure 3. Box-whiskers plots over the amount of mineral nitrogen in the top soil and sub soil at the 24 sites in November in the early tilled treatment. The line indicates the median, the box the 25th/75th percentile, the whiskers the 10th/90th percentile and dots individual outliers.

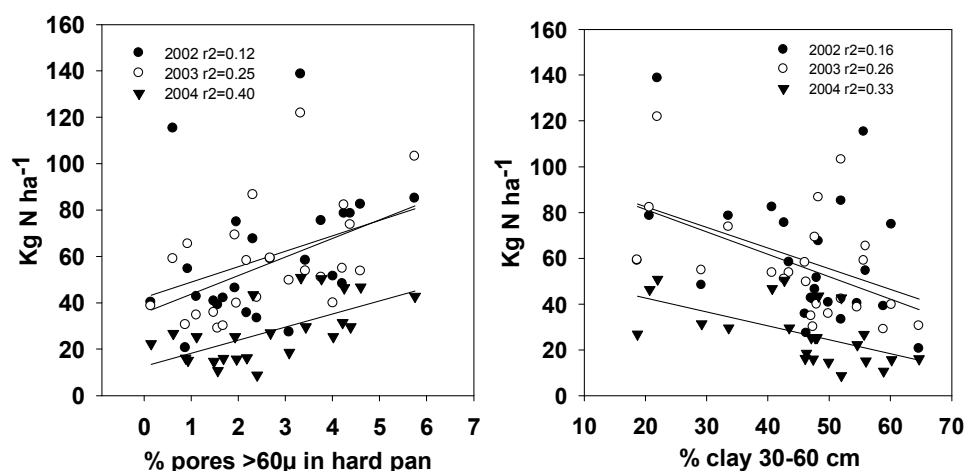


Figure 4. Year wise correlation plots between mineral nitrogen in the profile down to 90 cm and large pores or clay below the top soil, respectively.

Large pores and clay content throughout the profile and total N in the top soil explained the total amount of mineral N in November in the early tilled treatment to 60, 69 and 65% 2002, 2003 and 2004, respectively. Most important were pores $>60\mu$ in the hard pan and clay content in the upper sub soil (Figure 4). The correlations were not significant ($p=0.05$) 2002 and strongest 2004.

Conclusion

The most important conclusion from this project is that N mineralization in clay soils, due to tillage, does not differ from that in light textured soils. The increase in mineralization is as high as for light textured soil. However, the amount of N in the profile was much lower in November when autumn was not dry. We found it most probable that this was due to denitrification losses as there were no increased amounts of mineral N in the subsoil in the wet autumn and there was no reason to suspect a large decrease in mineralization this year. This was also supported by relationships between increased amounts of large pores and low clay content on one side and higher levels of mineral N in the top soil on the other as this promotes aeration and rapid drainage of excess water. This indicates that the risk for losses are not substantially smaller in clay soils compared with sandy soils, but the main mechanism is likely to be denitrification rather than leaching.

References

- Adu JK, Oades JM (1978) Utilization of organic materials in soil aggregates by bacteria and fungi. *Soil Biology and Biochemistry* **10**, 117-122.
- Hassink J (1992) Effects of soil texture and structure on carbon and nitrogen mineralization in grassland soils. *Biology and Fertility of Soils* **14**, 126-134.
- Stenberg M, Myrbeck Å, Lindén B, Rydberg T (2005) 'Inverkan av tidig och sen jordbearbetning under hösten på kväve mineraliseringen under vinterhalvåret och på utlakningsrisken på en lerjord. Rapport Nr 3'. (Avdelningen för precisionsodling: SLU. Skara).

Rock powder solubilization by *Aspergillus niger* as a source of potassium for agroecological systems

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Abstract

The objective of this work was to test the potassium (K) solubilization from minerals of an alkaline ultramafic rock powder by two strains (CCT4355 and CCT911) of *Aspergillus niger*. The experiment was carried out in triplicate in 250 mL erlenmeyer flasks over a period of 35 days. Soluble K, titratable acidity and pH were analysed and the solubilization rate (SR) was calculated relative to the total K in the rock powder (2.921 mmol/L). The data obtained showed that both strains of *A. niger* fungus have high potential of K solubilization and could be used as an alternative for small farmers to produce biofertilizers using rock powder.

Key Words

Soil remineralization, K biosolubilization, biofertilizers.

Introduction

The natural fertility of soils is directly connected to the availability and the release of chemical nutrient elements from the available rocks to the soil and it is influenced by pH, grain size, structure, porosity, permeability and organic matter content. Stonemeal practice, based on weathering and soil formation processes, is especially interesting for family farmers who want to conserve the land and wish to redesign the productive system following agroecological principles. Nevertheless, the long period demanded for the alteration of the minerals and the availability of important elements for plant nutrition makes this alternative unfeasible. Reports are found on satisfactory results for potassium (K) and phosphorus (P) solubilization by molds such as *Aspergillus*, *Penicillium* and *Fusarium*; and bacteria such as *Bacillus*, *Pseudomonas* and *Micrococcus* (Gaur 1990). The mould *Aspergillus niger* is known for its ability to solubilise P in rocks due to organic acid production, especially citric acid (Nahas *et al.* 1990; Vassileva *et al.* 1998). The use of microorganisms in association with rock powder could be an alternative to small farmers for obtain biofertilizer, using local materials. The objective of this work was to test the K solubilization from minerals of an alkaline ultramafic rock powder by two strains (CCT 4355 and CCT 911) of *Aspergillus niger*.

Materials and methods

The rock powder used was an alkaline ultramafic rock powder from Lages, Santa Catarina, Brazil, with 3.44 dag/kg K₂O (Barbosa-Filho *et al.* 2006; Moreira *et al.* 2006), presenting a grain size between 0.002-0.05 mm. Two *in vitro* experiments were carried out on a laboratory scale. The assays were carried out in triplicate in 250-mL erlenmeyer flasks with 50 mL of medium and 200 mg of rock powder, inoculated with *A. niger* spores (1.6×10^7 spores/mL) at 30°C, 160 rpm for 35 days of incubation. The culture medium contained sodium citrate (2.85g/L), NH₄SO₄ (1g/L), MgSO₄·7H₂O (0.5 g/L), CaCl₂ (0.132 g/L), glucose (10g/L), distilled water (1 L) and pH adjusted to 7.0 with NaOH 0.05 N. Two strains of *Aspergillus niger* were used (CCT4355 and CCT911) and three treatments (T1 = *A. niger* + medium; T2 = rock powder + medium; T3 = rock powder + *A. niger* + medium) were designed. Soluble K was determined by flame emission photometry, pH using a digital pH-meter, and titratable acidity by titration of the samples to pH 7 with 0.05M NaOH solution. The solubilization rate (SR) was calculated relative to the total K concentration in the rock powder.

Results and discussion

Both strains (CCT911 and CCT4355) solubilised K from the rock powder, and the results obtained were significantly different at the 5% level (Table 1 and Figure 1). The behaviour of each strain varied, in such a way that the K concentration, pH, titratable acidity and the SR were significantly different comparing the three treatments (Table 1).

Table 1. Average comparison by Tukey's test at 5% of significance for potassium concentration (K), pH, titratable acidity (TA) and solubilization rate of potassium (SR) in the culture medium with two strains of *A. niger* (CCT911 and CCT4355), during 35 days, at 30°C, 160 rpm.

Incubation time (days)	K (mmol _c /L)	pH	TA (mmol _c /L)	SR (%)
Strains				
CCT 911	0.96 a	5.59 a	18.84 a	32.73 a
CCT4355	0.88 b	6.06 b	9.05 b	30.17 b
Treatments				
T1	0.53 a	4.09 a	34.30 a	18.27 a
T2	0.73 b	7.15 b	7.16 b	25.00 b
T3	1.49 c	6.23 c	0.38 c	51.08 c

T1 = *A. niger* + medium; T2 = rock powder + medium; T3 = rock powder + *A. niger* + medium. Averages followed by different non-capitalized letters in the lines differ significantly at 5%.

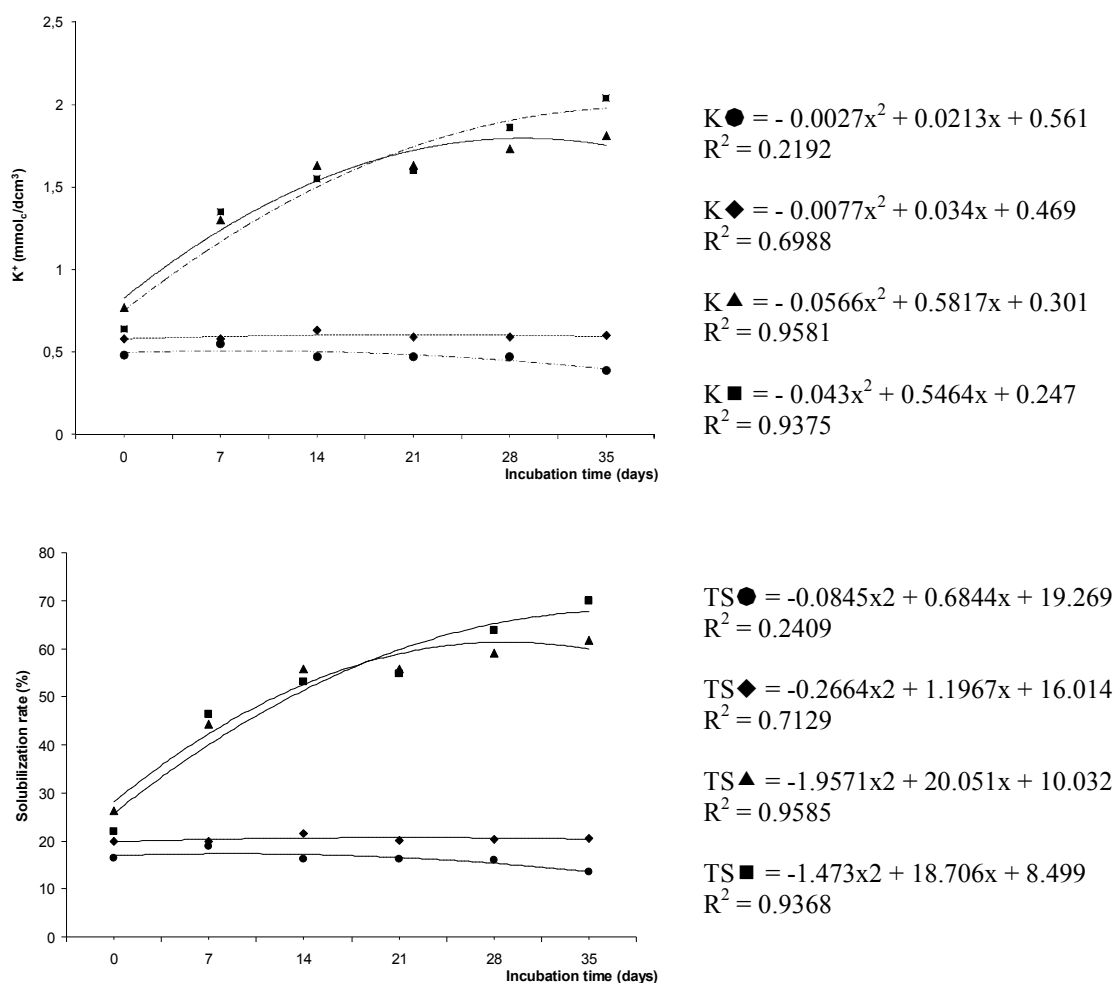


Figure 1. Potassium concentration (K) and solubilization rate of potassium (SR) in the culture medium with two strains of *A. niger* (CCT911 and CCT4355), during 35 days, at 30°C, 160 rpm. (◆ = CCT911 + medium; ● = CCT4355 + medium; ▲ = rock powder + CCT911 + medium; ■ = rock powder + CCT4355 + medium).

Approximately 70% of the K released was solubilised after 35 days of incubation of CCT4355 in liquid medium. When the strain was CCT911, the solubilization rate was higher than CCT4355 up to 21 days. After this period, CCT 4355 was more efficient in K solubilization than CCT 911. Lopes-Assad *et al.* (2006) have verified as much as 53.7% of SR in assays with the strain CCT4355 using alkaline ultramafic rock after 21 days of incubation. There was a significant increase in the titratable acidity and decrease in the medium pH in the treatments where the *A. niger* was inoculated, indicating that this fungus produces acids, as had been found by Nahas *et al.* (1990) and Vassileva *et al.* (1998). Lian *et al.* (2007) have studied a strain of the thermophilic fungus *Aspergillus fumigatus* cultured with K-bearing minerals to determine if microbe–mineral interactions enhance the release of mineral K. They observed that the K solubilization rate showed a

positive dependence upon pH when fungi and minerals were mixed directly, and exhibited no correlations with solution acidity if cell–rock contact was restrained. Concerning the use of rock powder in agricultural systems, of particular importance is soil pH; P (and K) will be released more quickly in moderately acid soils than in neutral or alkaline soils. Supanjani *et al.* (2006) studied the direct applications of P rock and K rock in conjunction with P-solubilizing bacteria and K-solubilizing bacteria for cultivation of hot pepper *Capsicum annuum* and verified a variety of benefits (improved nutrient uptake, higher biomass harvest and fruit yield) and a promising, sustainable alternative to the use of classical fertilizers. *Aspergillus niger* offers a great potential for biotechnological applications, especially in the production of organic acids and solubilization of rocks for biofertilizers.

Conclusion

The data obtained showed that *Aspergillus niger* has high potential of K solubilization and could be an alternative for small farmers to produce biofertilizers using rock powder.

References

- Barbosa-Filho MP, Fageria NK, Santos DF Couto PA (2006) Aplicação de rochas silicáticas como fontes alternativas de potássio para a cultura do arroz de terras altas. *Espaço & Geografia* **9**, 63-84.
- Gaur AC (1990) Phosphate solubilizing microorganisms as biofertilizers. pp. 16-72. (Omega Scientific Publisher: New Delhi).
- Lian B, Wang B, Pan M, Liu C, Teng HH (2007), Microbial release of potassium from K-bearing minerals by thermophilic fungus *Aspergillus fumigatus*. *Geochemistry Cosmochimica Acta* **72**, 87-98.
- Lopes-Assad ML, Rosa, MM, Erler G, Ceccato-Antonini, SR (2006) Solubilização de pó-de-rocha por *Aspergillus niger*. *Espaço & Geografia* **9**, 1-16.
- Moreira A, Castro C, Oliveira FA, Salinet LH, Sfredo GJ (2006) Efeito residual de rochas brasileiras como fertilizantes e corretivos da acidez do solo. *Espaço & Geografia* **9**, 163-177.
- Nahas E, Banzatto DA, Assis LC (1990) Fluorapatite solubilization by *Aspergillus niger* in vinasse medium. *Soil Biology and Biochemistry* **22**, 1097-1101
- Supanjani HHS, Jung JS, Lee KD. (2006) Rock phosphate-potassium and rock-solubilising bacteria as alternative, sustainable fertilizers. *Agronomy for sustainable development* **26**, 233-240.
- Vassileva M, Vassilev N, Azcon R (1998) Rock phosphate solubilization by *Aspergillus niger* on olive cake-based medium and its further application in a soil-plant system. *World Journal of Microbiology and Biotechnology* **14**, 281-284.

Shoot and root growth and potassium concentration of maize as affected by potassium fertiliser placement

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Abstract

Banding of fertilisers is becoming a necessary part of conservation tillage. Unfortunately, when nutrients are placed in a band there is the possibility of insufficient root contact for optimum uptake. For nitrogen (N) and phosphorus (P), this issue is addressed through the well understood plant response of root proliferation. In contrast, there has been little work done on fractional fertilising of potassium (K), and the existing work indicates that K does not promote root proliferation. A pot trial with treatments consisting of six different fractional soil volumes fertilised with K was set up to determine the effect of fractional fertilisation of K on the plant uptake of K, root morphology and shoot biomass. Root proliferation occurred in treatments with a band application of fertiliser and with 6.25 and 12.5% of soil volume fertilised. There was no effect from fractional fertilisation on plant uptake of K or shoot biomass production. Plants were able to adapt to the resource environment and achieve adequate uptake of K regardless of the soil volume fertilised.

Key Words

Potassium, root proliferation, potassium fertiliser, *Zea mays*

Introduction

Conservation tillage has been widely adopted in the South Burnett, (Queensland, Australia) for the agronomic benefits it confers. One adverse effect of this adoption is the stratification of K in the soil profile, which, combined with K depletion, is leading to the appearance of K deficiency in crops (Bell *et al.* 1995). Clearly a means of supplying K which overcomes stratification, whilst preserving the benefits of conservation tillage, is required. One option is to band K fertilisers, possibly at depth. However, banding K may not result in sufficient K uptake, as placing fertiliser in a small soil volume will supply few roots since the mobility of K in soil can be limited. White (2002) and Bell *et al.* (1995) showed that K in Ferrosols in the South Burnett region is immobile, resulting in banded K fertilisers remaining where they are placed, reducing the soil volume containing sufficient K for plant uptake.

Plants respond to enriched nutrient patches in two ways; a morphological response (root proliferation) or a physiological response (increased uptake rate). An increase in the uptake rate of P, N and K in enriched zones has been shown by a number of authors (Robinson 1994), but this may be insufficient to meet the plant nutrient requirements; up to 50% of maize roots required access to K in solution for sufficient K uptake (Claassen and Barber 1977). The effectiveness of banding N and P fertiliser is, in part, attributable to the root proliferation. There are numerous reports of root proliferation in response to N and P (Hodge *et al.* 1999), and indicating that proliferation is dependent on the strength of the enriched zone relative to background fertility (Hodge 2004). Little work has been done on the ability of K to promote root proliferation. Most published studies have been in solution culture, have used maize (*Zea mays*) as the test species, and have found that K does not promote root proliferation (Brouder and Cassman 1994; Claassen and Barber 1977).

Information on the effect of K placement on root growth and morphology is important for evaluating the smallest soil volume that can be fertilised with K, without decreasing K uptake to a level that will give less than maximum yield. The objective of this work is to determine optimum placement of K for greatest recovery of K by the crop.

Methods

A pot trial consisting of six treatments (four replicates), was set up as a completely randomised design. Treatment 1 (control), had no added K. The other five treatments had 1.36 g of K/pot as KCl, mixed with different volumes of soil; for Treatment 2 as a band placement, while the other treatments had K mixed with 6.25%, 12.5%, 25% and 50% of the total soil volume (Treatments 3, 4, 5 and 6 respectively). The pots (300 mm diam.) were filled with 15 kg of a low K, Brown Ferrosol soil from the South Burnett. The soil was

ground to less than 2mm to allow consistency of packing and ease of washing roots. Basal nutrients (N-140 mg/kg, P-470 mg/kg, Ca-28 mg/kg, Mg-28 mg/kg, Zn-5 mg/kg, Cu-5 mg/kg, B-1 mg/kg and Mo-0.189 mg/kg) were added before the appropriate soil volumes for each treatment were separated and mixed with KCl. The fertilised soil volumes were positioned in the middle of the pots and were the depth of the soil profile for the 25 and 50% of soil volume fertilised with the dimensions of the other volumes shown in Figure 5. The fertilised soil sections were separated from the rest of the soil in the pot with loose weave shade cloth. This allowed easy separation of the soil section for collection of roots. Four germinated *Zea mays* seeds were planted, two on each side of the fertilised soil sections, which once established were thinned down to two, one each side of the fertilised soil section.

At 40 days after planting the trial was harvested with measurements of fresh and dry weights of the whole plant top as well as roots of each soil section. The fresh weights of the roots were used to determine root length by using linear correlations developed from previous work using the same *Zea mays* seeds. Plant tissue K concentrations of the shoots were also determined. Differences between the treatments in plant tissue K concentrations, shoot dry weights, root length densities within fertilised zones and total root lengths were determined using one way ANOVAs calculated using Minitab (Anon 2004).

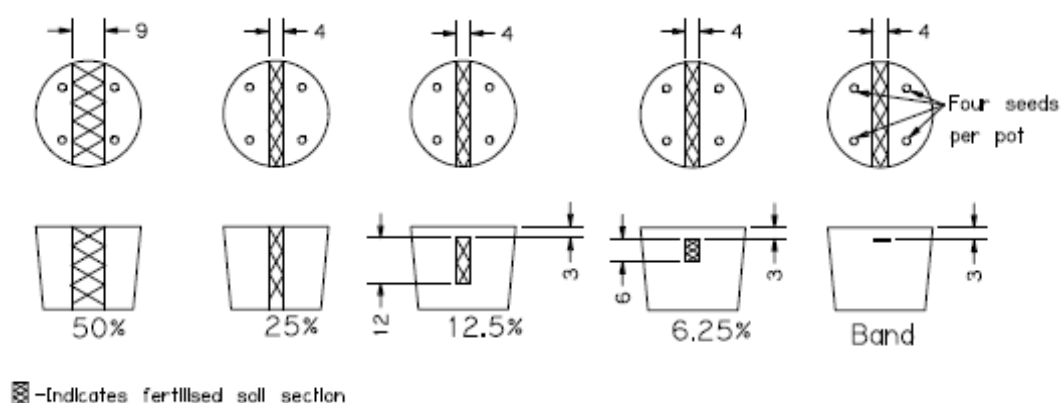


Figure 5: Arrangement of fertilised soil sections in the soil profile. Dimensions are shown in cm.

Results and discussion

Fractional fertilisation of the soil had no significant effect on the total root length ($p = 0.290$) (Table 11). However, fractional fertilisation had a significant effect on the root distribution ($p = 0.001$), with Treatment 3 (6.25%) producing the greatest root length density in the fertilised soil section (Table 11). Root proliferation was also apparent in Treatment 4 where 12.5% of soil volume was fertilised (Table 1 and Figure 2). Proliferation can not be attributed with certainty to K, but may have been a result of an indirect effect, for example as a result of preferential adsorption of K^+ over NH_4^+ increasing NH_4^+ in solution in the band and promoting root proliferation. No proliferation occurred with 25 or 50% of the soil fertilised.

The soil factors that dictate the promotion of root proliferation are the soil volume fertilised and the ratio of the nutrient concentration in the fertilised zone to the nutrient concentration in the unfertilised zone. In this pot trial the same quantity of K fertiliser was applied to different soil volumes, resulting in ratios of K concentrations in the fertilised zone to the K concentration in the unfertilised zone of 113, 18, 9, 4.5, and 2.26 for Treatments 2 to 6. Root proliferation was promoted when the ratio of the K concentrations in the fertilised zone to the K concentration in the unfertilised zone is greater than 9 (Treatments 2, 3 and 4). Root proliferation does not appear to be promoted when the ratio is equal to or less than 4.5 (Treatments 5 and 6).

Table 11. Total root length and root length density in fertilised and unfertilised soil.

Treatment (% soil volume fertilised)	Mean root length density (mm/g of soil)		Mean root length (cm)	
	Fertilised soil section [#]	Unfertilised zone	Fertilised soil section [*]	Total
1	N/A	3.2	N/A	4867
2 (band)	5.88 ^{ab}	4.24	88 ^a	6379
3 (6.25)	7.95 ^a	3.87	745 ^b	6193
4 (12.5)	5.10 ^{bc}	3.56	957 ^b	5634
5 (25)	2.80 ^{cd}	3.83	1050 ^b	5663
6 (50)	2.22 ^d	4.20	1706 ^c	4853

[#]*Numbers in the columns with the same letter are not significantly different at 95% confidence intervals.

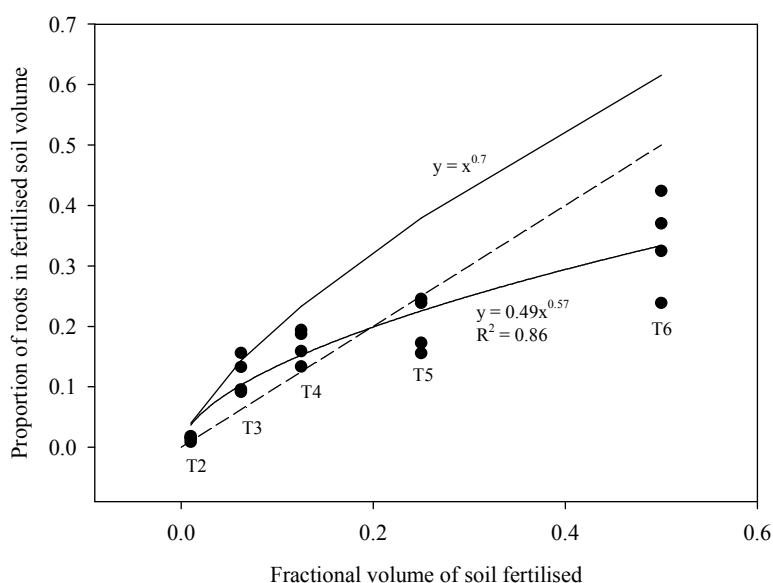


Figure 2. Effect of fraction of soil treated with K on the fraction of the roots in K-treated soil with the line of best fit for treatments 2 to 6. The other line shown, $y = x^{0.7}$, is the relationship for maize in N fertilised soil (Anghinoni and Barber 1988). The dashed line is a 1:1 line and is what would be expected if there was no response to K.

There were no foliar symptoms of K deficiency, and only a small visual difference in growth (Treatment 1 was shorter). The shoot dry weights showed no significant difference between the treatments ($p = 0.776$). However, there was a significant treatment effect ($p < 0.0009$) for tissue K concentration; Treatment 1 having a significantly lower value than other treatments. The Treatment 1 tissue K concentration of 1.05% is below the critical value for whole shoot at 42 days after sowing of 1.75 to 2.08%, (Reuter and Robinson 1997). With Treatments 2 to 6, where K was applied, there was no significant difference in the plant uptake of K. In all of these treatments adequate K was absorbed with plant tissue K concentrations ranging from 1.97% to 2.4%.

The band applied treatment had a lower root length density and a smaller root length in the concentrated soil section than the other treatments (Table 1). As this treatment also had the same plant uptake of K, there would have been physiological plasticity (increased uptake rate) to make up for the lower root length in and around the fertiliser band. The soil solution K concentration must have been sufficiently high to increase uptake rate to a point that replaced the smaller root volume in and around the fertiliser band.

Root proliferation in the treatments with 6.25 and 12.5% of the soil volume fertilised resulted in a root length in the fertilised soil that was less than but not significantly different to the root length in the fertilised soil volume of the treatment with 25% soil volume fertilised. The treatment with 25% of the soil volume fertilised also showed no root proliferation in the fertilised section (Table 1 and Figure 2). This indicates that the root volume in the fertilised section provided sufficient contact with the applied fertiliser for adequate K uptake.

The objectives of this pot trial were to determine the effect of fractional fertilisation of K on the plant K uptake and the root morphology. From this data, the soil volume to fertilise with K for optimum plant uptake of K and maximum shoot biomass could be determined. The effect of fractional fertilisation of K was to increase the plant uptake of K. If the soil solution K concentration and surrounding exchangeable K were insufficient for the soil to buffer the increased uptake rate to allow adequate plant uptake, then root proliferation was promoted until a root length was achieved to allow adequate uptake with both increased plant uptake rate and root proliferation. In essence, the *Zea mays* plants were able to adapt to the resource environment and achieve adequate uptake of K. Thus, there was no effect of fractional fertilisation on plant uptake of K or shoot biomass production.

It then follows that there is no optimum soil volume to fertilise for optimum K uptake and shoot biomass growth. However, if consideration is given to the energy expenditure required with physiological and morphological plasticity, then the optimum soil volume to fertilise would be 25%, the lowest soil volume treatment with no root proliferation. Although it should be noted that in this trial there was no adverse effect on shoot biomass up to the 40 days after sowing growth stage from the energy expended, with plasticity responses (increased uptake rate) to fractional fertilisation. This optimum soil volume to fertilise can be compared with 12.5% for the uptake of P by soybean (Borkert and Barber 1985) and 50% for the uptake of P by maize (Anghinoni and Barber 1980). This shows the variability that is involved with fractional fertilisation.

References

- Anghinoni I, Barber SA (1980) Predicting the most efficient phosphorus placement for corn. *Soil Science Society of America Journal* **44**, 1016-1020.
- Anon (2004) 'Minitab 14; student release.' (Minitab Inc; State College: PA).
- Bell MJ, Harch GR, Bridge BJ (1995) Effects of continuous cultivation on Ferrosols in subtropical southeast Queensland. I. Site characterisation, crop yields and soil chemical status. *Australian Journal of Agricultural Research* **46**, 237-253.
- Borkert CM, Barber SA (1985) Soybean shoot and root growth and phosphorus concentration as affected by phosphorus placement. *Soil Science Society of America Journal* **49**, 152-155.
- Brouder SM, Cassman KG (1994) Cotton root and shoot response to localized supply of nitrate, phosphate and potassium. Split pot studies with nutrient solution and vermiculitic soil. *Plant and Soil* **161**, 179-193.
- Claassen N, Barber SA (1977) Potassium influx characteristics of corn roots and interaction with N, P, Ca, and Mg influx. *Agronomy Journal* **69**, 860-864.
- Hodge A (2004) The plastic plant: root responses to heterogeneous supplies of nutrients. *New Phytologist* **162**, 9-24.
- Hodge A, Robinson D, Griffiths BS, Fitter AH (1999) Why plants bother: Root proliferation results in increased nitrogen capture from an organic patch when two grasses compete. *Plant Cell and Environment* **22**, 811-820.
- Reuter DJ, Robinson JBD (1997) 'Plant analysis: An interpretation manual.' (CSIRO Publishing: Collingwood, Vic.)
- Robinson D (1994) The responses of plants to nonuniform supplies of nutrients. *New Phytologist* **127**, 635-674.
- White J (2002) Potassium distribution in ferrosols and its influence on rain-fed crop production in the South Burnett region of Queensland. PhD thesis, University of Queensland.

Soil chemical attributes affected by superficial application of lime and silicate

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Abstract

The experiment carried out in Botucatu-SP, Brazil, on a clayey Oxisol was to evaluate the effects of lime and Ca+Mg silicate on soil chemical attributes, months after 6 superficial applications. The treatments consisted of two sources for acidity correction (lime and Ca+Mg silicate) and a control. Organic matter, pH, base saturation, extractable H+Al, P, Ca, Mg, Al³⁺ and Si levels were evaluated. Results were submitted to variance analysis and means were compared by the t test (LSD) at a probability level of 5%. Silicate and lime increased pH down to 0.10-0.20m and 0.00-0.05m, respectively. Both treatments decreased H+Al levels at the depths 0.00-0.05 and 0.10-0.20m. Ca and Mg levels increased at the depths 0.00-0.20 and 0.00-0.10m, respectively. Silicate increased extractable P levels down to 0.10m, emphasizing the influence of Si on P availability.

Key Words

Slag, calcium carbonate, base leaching.

Introduction

Liming is essential to successfully obtain high crop yields due to great benefits in soil acidity correction, Ca and Mg supply and aluminum toxicity decrease. In no tillage system, liming is superficially applied, with no incorporation. However, this method is still dubious, because of lime's low water-solubility and reactivity. Although lime is the most used product for soil correction, Ca and Mg silicates provided by slag are also efficient. These materials are similar to lime. Besides increasing pH, exchangeable Ca and Mg and P availability, they also decrease Fe, Al and Mn toxicity. These products also provide Si, which is not considered an essential element, but it is beneficial to some crops. The use of these materials in no tillage systems is a feasible alternative for soil acidity correction, considering that some silicate sources are more soluble than lime and thus contribute with better and faster correction in deeper layers, providing Si to plants. This study objective was to evaluate soil chemical attributes affected by superficial application of lime and silicate.

Methods

The experiment was carried out on Lageado Experimental Farm, College of Agricultural Sciences - UNESP, in Botucatu-SP, Brazil. The soil was a deep acid clayey Oxisol. According to the Köppen classification, climate is Cwa, with dry winter and hot rainy summer. The experimental design was a completely randomized block with sixteen replications. Treatments consisted of two sources for soil acidity correction (lime and Ca+Mg silicate) and a control. Plots were 5.4m wide and 10m long, totaling 54m². At random, six samples in the useful area of each subplot were taken in the interrows of the previous crop, to obtain a composite sample. As correction sources, dolomitic lime (ECC = 90%, CaO = 36% and MgO = 12%), Agrosilício[®] (Ca+Mg silicate / ECC = 80%, CaO = 34%, MgO = 10% and SiO₂ = 22%). Dolomitic lime was obtained in Formiga-MG, Brazil, because it was similar to the Agrosilício[®] for Ca and Mg levels. Doses of 4.0 and 4.5 t/ha of dolomitic lime and Ca+Mg silicate, respectively, were applied superficially, after moisture correction. In the same area, the soybean crop was cultivated. Soil chemical characteristics (pH, base saturation, H+Al, P, Ca, Mg and Al³⁺) were evaluated 6 months (April of 2007) after the application, at the depths 0.00-0.05m, 0.05-0.10m, 0.10-0.20m, 0.20-0.40m and 0.40-0.60m. Samples were dried and sieved and analyzed for pH, EC and extractable elements according to Raij *et al.* (2001). Data was submitted to variance analysis. Means for lime and silicate applications were compared by the t test (LSD) at a probability level of 5%. Chemical attributes of the soil profile, sampled 6 months after application, are shown individually for each product (lime, silicate and control, with no application).

Results

In Figure 1 are the pH (A), H+Al (B), Al³⁺ (C), base saturation (V%, D), Ca (E), Mg (F), P (G) and Si (H) values 6 months after application. For pH results, it was observed that both sources were efficient in the

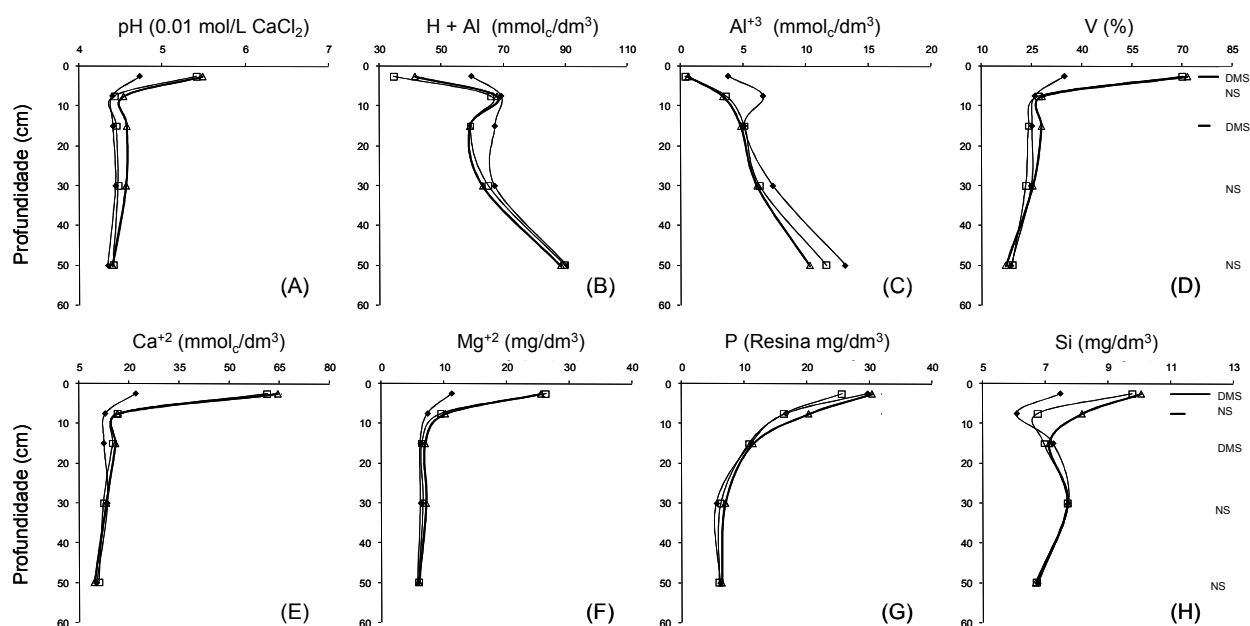


Figure 1. pH (A), H+Al (B), Al^{3+} (C), base saturation (V%, D), Ca (E), Mg (F), P(G) and Si (H) levels in soil affected by materials used for acidity correction (lime - $\square$; silicate - Δ ; control - $\diamond$).

upper layer (0.00-0.05m). Conversely, at the depth 0.05-0.20m, only the silicate increased pH compared to the control. Corrêa *et al.* (2007) studied the effects of lime and silicate in soil profile and reported that silicate increased pH down to 0.40m by only three months after application. Meanwhile, the same dose of lime increased pH down to 0.05m. The authors inferred that silicate application increases ion mobility faster than lime. Alcarde (1985) concluded that silicate is 6.78 times more soluble than calcium carbonate and thus the benefits are observed in deeper layers faster than other materials. Silicate is considered a feasible alternative for superficial application aimed at soil acidity correction in no tillage systems.

Aluminum toxicity limits plant growth in acid soils, inhibiting root development and, consequently, nutrient uptake. H+Al values (Figure 1B) were significantly affected by the correction material. It was observed that soil potential acidity was lower at the depths 0.00-0.05 and 0.10-0.20m, which indicates the beneficial effects of these products in decreasing acidity values down the profile. Similar effects were found for exchangeable Al (Figure 1C), but only in the two upper layers. This occurs due to an increase in hydroxyl concentration, reacting with H^+ from the soil solution, resulting in Al precipitation as $Al(OH)_3$, which is not toxic to plants (Pavan and Oliveira 2000).

Figure 1D showed that base saturation (V%) was considerably affected by the products for the depth 0.00-0.05m, reaching 70%, which is the value sought for the calculation of acidity correction. On the other hand, in the depth 0.10-0.20m, only the value for silicate application was higher than the control. These effects in deeper soil layers may be related to a higher water-solubility compared to lime and also because the area was already under an established no tillage system. As for Ca (Figure 1E), levels were higher down to 0.10-0.20m whenever any products were applied. The effects on Mg levels (Figure 1F) were observed only down to 0.05-0.10 m. Ca and Mg leaching occurs because when pH is increased in superficial layers, the HCO_3^- ion followed by Ca and Mg is mobilized down to deeper layers for acidity reaction, increasing the levels of these nutrients. In field conditions, Corrêa *et al.* (2007) found similar results. The authors observed higher Ca and Mg levels for the depth 0.00-0.10m only three months after silicate application. On the contrary, effects were only for the depth 0.00-0.05m when the same dose of lime was applied.

Silicate application increased extractable P levels down to 0.05m compared to liming, but it did not differ from the control (Figure 1G) However, silicate application increased P levels in the depth 0.05-0.10m compared to the other treatments. Pulz *et al.* (2008) studied the application of lime and silicate to poor soils and observed that P availability increased when soil acidity was corrected with silicate. According to Plucknet (1972), silicate application increases P solubility in soil and decreases fixation. Silicon (Figure 1H) increased in the superficial layer for both materials, even considering that lime does not provide this element directly. Liming increased Si levels in the depth 0.00-0.05m, probably due to solubilization of silica

components, because of pH increase and/or due to lower capacity of absorption sites, keeping higher levels in the soil solution. Nevertheless, for both Si values in the depth 0.05-0.10m (Figure 1H) and pH (Figure 1A), lime application did not show any effects, and only silicate increased Si levels. In deeper layers, both materials affected Si levels compared to the control. Positive effects of silicate on Si levels were expected, because it is considered an important source of this element for plants. Pulz *et al.* (2008) also observed higher Si levels for silicate application compared to liming.

Conclusion

Silicate and lime increased pH down to 0.10-0.20m and 0.00-0.05m, respectively. Both treatments decreased H+Al levels in the depths 0.00-0.05 and 0.10-0.20m. Silicate and lime increased Ca and Mg levels in the depths 0.00-0.20 and 0.00-0.10m, respectively. Silicate increased P levels down to 0.10m, emphasizing the Si influence on P availability.

References

- Alcarde JC (1985) Corretivos da acidez dos solos: características de qualidade. In 'Seminário sobre corretivos agrícolas'. (Ed E Malavolta) pp.97 – 117. (Piracicaba: Fundação Cargill).
- Corrêa JC, Büll LT, Crusciol CAC, Marcelino R, Mauad M (2007) Correção da acidez e mobilidade de íons em Latossolo com aplicação superficial de escória, lama cal, lodos de esgoto e calcário. *Pesquisa Agropecuária Brasileira* **42**, 1307-1317.
- Pavan MA, Oliveira EL (2000) Calagem em plantio direto. In: Encontro Nacional de Plantio Direto na Palha, 7, 2000, Foz do Iguaçu. *Resumos*. pp.125 – 129. (Foz do Iguaçu: Federação Brasileira de Plantio Direto na Palha).
- Plucknett DL The use of soluble silicates in Hawaii agriculture. *Univ. Queenl. Pap.* **1**, 203-223, 19
- Pulz AL, Crusciol CAC, Lemos LB, Soratto RP (2008) Influencia de silicato e calcário na nutrição, produtividade e qualidade de batata sob deficiência hídrica. *R. Bras. Ci. Solo* **32**, 1651-1659.
- Raij B van, Andrade JC, Cantarella H, Quaggio JA (2001) 'Análise química para avaliação da fertilidade do solo'. (Campinas: Instituto Agronômico).

Soil chemical attributes, technological quality and yields of sugar cane submitted to organic and mineral fertilizers

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Abstract

The experiment was carried out to evaluate the effects of organic and mineral fertilizers on soil chemical properties, technological quality and yield of sugar cane, performed in a field experiment in the city of Dracena, São Paulo, Brazil. The experimental design was a randomized block with four replications. For the treatments two compounds were produced. Compound 1: sugar cane bagasse (70%) + ashes (10%) + byproduct of tanning (20%) + decomposing microorganisms; Composite 2: sugar cane bagasse (70%) + ashes (10 %) + byproduct of frigorific (20%) + decomposing microorganisms. The evaluated treatments were the following: 1) 275 kg/ha (half dose) of mineral fertilizer 5 25 25; 2) 10 t/ha of compost 1 + treatment 1, 3) 15 t/ha of Compound 1 + 1 treatment; 4) 20 t/ha of compost 1 + treatment 1, 5) 10 t/ha of compost 2 + treatment 1, 6) 15 t/ha of compost 2 + treatment 1, 7) 20 t/ha of compost 2 + treatment 1. There was a change among the sources in calcium content in the soil only for the application of 15 t/ha of compost, however, all values are considered low. There was no difference in the phosphorus in the soil between the doses of compounds. The concentration of P in soil is directly proportional to the doses of organic compost. The pH, organic matter, K, Mg, S-SO₄⁻², Al, B, Cu, Mn, Fe and Zn in soil were not affected by the doses of organic compost. The dose of 15 t/ha of organic compound associated with 275 kg/ha of mineral fertilizer (5 25 25) gave the best response in the production of stems of sugar cane. The average doses of organic compost with the byproduct of frigorific showed higher cane yield. Technical quality was not affected by the treatments.

Key Words

Composting, *Saccharum* spp., plant nutrition.

Introduction

With the growth of agribusiness in Brazil, the volume of organic waste is increasing. Such waste can be recycled through composting and used sustainably since they are sources of raw material for production of organic fertilizers. If these residues do not have a suitable target, they can cause problems to sanitation, through contamination of water, soil, plants and animals. There is a range of organic waste that can be applied in agriculture, for example, cattle manure, chicken manure, swine manure, filter cake, castor bean, green manure, peat, among others. Composting is a viable treatment, allowing the co-processing of various waste products generating good agronomic characteristics (Fernandes *et al.* 1993). Composting can be defined as a biological process, aerobic and controlled by means of which it is possible humified organic material, resulting in the final product as organic compost. During the thermophilic phase of composting, pathogens are eliminated from the mass of the compound, and this is a fundamental process from the standpoint of health (Matos *et al.* 1998). The need of additional mineral fertilization with the application of organic waste may be compared with the nutritional requirement and level of crop productivity, soil properties, type and quality of the material (Abreu Junior *et al.* 2005). The necessity of agricultural sectors to meet domestic and external demand is always stimulating the need for increasing productivity through minimizing environmental impacts. For this goal to be achieved it is essential there is good management of soil and adequate fertilization, to provide conditions for the development of the best features of the plant. This study aimed to evaluate the effects of organic and mineral fertilizers on soil chemical properties, technological quality and yield of sugar cane.

Methods

The experiment was carried out on a plantation of sugar cane variety RB835486, located in Dracena, São Paulo, Brazil. The soil of the area was classified Ultisoil. Chemical analysis was performed on soil samples collected in the 0 - 20 cm deep, with the following chemical properties: pH (CaCl₂) 4.6, organic matter, 12.0 g/dm³; P (resin), 3, 0 mg/dm³; S-SO₄⁻², 1.0 mg/dm³; K (resin), 1.4 mmol/dm³; Ca (resin), 6.0 mmol/dm³; Mg (resin), 4.0 mmol/dm³; Al, 2.0 mmol/dm³; H + Al, 18.0 mmol/dm³; sum of bases, 11.4 mmol/dm³; capacity cation exchange, 29.4 mmol/dm³; aluminum saturation, 0.15%; base saturation, 34.0%; B, 0.11 mg/dm³; Cu, 0.6 mg/dm³; Fe, 29.0 mg/dm³; Mn, and 7.4 mg/dm³; Zn, 0.9 mg/dm³. In turn, the results of size analysis were: Clay, 130 g/kg; silt, 20 g/kg sand, 850 g/kg.

The experimental design was a randomized block with four replications. Each plot was consisted of 6 rows of sugar cane with 15 meters long, spaced at 1.4 meters. For the treatments two compounds were produced. Compound 1: sugar cane bagasse (70%) + ash (10%) + byproduct of tanning (20%) + decomposing microorganisms; Composite 2: sugar cane bagasse (70%) + ashes (10 %) + product of frigorific (20%) + decomposing microorganisms. The treatments were: 1) 275 kg/ha (half dose) of mineral fertilizer 5 25 25; 2) 10 t/ha of compost 1 + treatment 1, 3) 15 t/ha of compost 1 + treatment 1, 4) 20 t/ha of compost 1 + treatment 1, 5) 10 t/ha compound 2 + treatment 1, 6) 15 t/ha of compost 2 + treatment 1, 7) 20 t/ha of compost 2 + treatment 1. The dose of the compound was calculated on dry basis.

The fertilizers (organic and mineral) were applied in the furrow before the placing of stems. For evaluation of treatments, the soil was sampled at the time of harvest the stalks at 0 - 20 cm depth. For technology assessment were collected 10 stems at harvest, which was performed without straw removal by burning. Soil analysis followed the methodology described by Raij *et al.* (2001) and technological analyzes followed Fernandes (2003). The results were statistically evaluated by analysis of variance, interactions with comparison of means at 5% probability by Tukey test, correlation and regression study.

Results

The organic compounds produced from the waste and by-products for a composting period of 35 days showed the following characteristics on a dry basis: The byproduct of tanning: 0.70% total N; 0.08% P₂O₅; 0.11% K₂O; 2.07% Ca; 0.11% Mg; 0.50% S; and 24/1 C/N ratio. Byproduct of frigorific: 2.14% total N; 4.43% P₂O₅; 0.20% K₂O; 6.74% Ca; 0.24% Mg; 0.12% S; and 11/1 C/N ratio. Examining the interaction between doses and sources of compost, it was found that for the 0 – 20cm soil only Ca showed a significant effect. For the use of the compost residue frigorific the calcium content in the soil was higher at 20 t/ha, different from the treatment with application of 0 and 15 t/ha (Figure 1). Results can possibly be attributed to variations in sampling, since only t/ha caused a reduction in calcium content in the soil, a value lower than for the treatment without application of organic fertilizer.

Phosphorus had an effect for the average doses of compost in the 0 - 20 cm, with the highest values with application of compost and no statistical difference between the two organic fertilizers applied. As can be seen from the results of the analysis of compounds, phosphorus levels are higher in the compost with the addition of frigorific residues from the value found in the inclusion of tannery waste. However, even with the use of compounds with different phosphorus levels the levels in the soil after one year of application were similar. Possibly, the action of organic acids, humic acids and alcohols, which provide substances such as phenols, contribute to increased nutrient availability. There was a positive linear response to both nutrients a dose of 20 t/ha of organic compost (Figure 1).

The other chemical characteristics showed no significant effects. pH was 4.5 to 4.7; organic matter, 11.6 to 12.1 g/dm³; K, 1.4 to 1.2 mmol/dm³; Mg, 2.2 to 2.3 mmol/dm³; S-SO₄⁻², 7.5 to 8.2 mg/dm³; Al, 4.6 to 4.8 mmol/dm³; B, 0.12 to 0.14 mg/dm³; Cu, 0.45 to 0.52 mg/dm³; Mn, 1.93 to 2.04 mg/dm³; Fe, 4.15 to 4.74 mg/dm³ and Zn, 1.09 to 1.13 mg/dm³. The highest yield of cane was for the use of 15 t/ha compound, which did not differ between the treatments with application of organic fertilizer, but differed from the treatment with zero dose of compost, which is an increase in production of 10%. This increase in production of stalks of sugar cane due to fertilization with organic compost can be attributed to several factors, such as nutrient supply, improvement in the physical structure of the soil, increasing microbial activity, water availability, soil aeration and larger roots, reflecting the increased vigor of plants (Magalhães *et al.* 2006). The interaction of all factors in different ways depends on soil and climate conditions and the variety of sugar cane.

The analysis of interaction between doses and sources of compounds indicated no significant difference, even though the preliminary analysis of the compound formed from frigorific had a higher concentration of nutrients. This result can be sustained by the introduction of organic material to soil, which provides a favorable environment for growth and production. The only difference was for the average of the sources of compost, with the highest straw yield for the treatments with compost generated by the inclusion of by-product of a frigorific (103.7 t/ha) compared to treatments with tannery compost (98.7 t/ha). The variables from technological analysis showed no difference between the treatments. Reducing sugars (glucose and fructose) 0.36 to 0.38%; total reducing sugars (sucrose, glucose and fructose) 17.65 to 18.54%; total recoverable sugar (TRS): 161.96 to 167.84 kg/t; reading sucrose: 85.00 to 88.25%; Purity: 84.20 to 93.21%; Fiber: 13.80 to 14.31%; Brix: 21, 97 to 22.65; Pol of sugar cane (sucrose apparent percentage): 16.41 to 17.27%.

Although there was statistical variation in the production of stems, TRS production per area was not significant in the analysis of interaction between doses and sources of compounds. In percentage terms, the treatment with high production of TRS was 15 t/ha of compost by-product of frigorific (17.59 t/ha) compared to treatment without compost (16.28 t/ha) was 8 %, which can become financially viable depending on the cost of mineral fertilizers. Evaluating the results of technological analysis, it was found that the increase in sugar yield due to higher straw yield in response to fertilization, treatments did not improve the technological quality of raw material ATR/ha and straw yield had a correlation of 0.90 with significance of $P < 0.0001$, while the correlation with for the concentration of ATR correlation was found.

Conclusion

Among the sources there was a change in calcium content in the soil only for the application of 15 t/ha of compost, however, all values are considered low; There was no difference between the doses of compounds in phosphorus in the soil; The concentration of P in soil is directly proportional to the doses of organic compost; The pH, organic matter, K, Mg, S-SO₄-2, Al, B, Cu, Mn, Fe and Zn in soil were not affected by the doses of organic compost; Averaged across treatments, the organic compound containing the byproduct of frigorific had a higher yield of cane; The productivity of sugar is mainly increased by a larger straw yield production rather than by improving technological quality

References

- Abreu Junior CH (2005) Uso agrícola de resíduos orgânicos potencialmente poluentes: propriedades químicas do solo e produção vegetal. *Tópicos Especiais em Ciência do Solo, Viçosa* **4**, 391-470.
- Fernandes F, Pierro AC, Yamamoto RY (1993) Produção de fertilizante orgânico por compostagem do lodo gerado por estações de tratamento de esgoto. *Pesquisa Agropecuária Brasileira* **28**, 567-574.
- Matos AT, Vidigal SM, Sediya MAN, Garcia NCP, Ribeiro MF (1998) Compostagem de alguns resíduos orgânicos, utilizando-se águas residuárias da suinocultura como fonte de nitrogênio. *Revista Brasileira de Engenharia Agrícola e Ambiental* **2**, 199-203.
- Raij Bvan, Andrade JC, Cantarella H, Quaggio JA (2001) 'Análise química para avaliação da fertilidade de solos tropicais'. (Campinas: Instituto Agrônomo).
- Magalhães MA, Matos AT, Deniculi W, Tinoco IFF (2006). Compostagem de bagaço de cana-de-açúcar triturado utilizado como material filtrante de águas residuárias da suinocultura. *Revista Brasileira de Engenharia Agrícola e Ambiental* **10**, 466-471.
- Fernandes, AC (2003) 'Cálculos na agroindústria de cana-de-açúcar. Piracicaba: STAB – Sociedade dos técnicos Açucareiros e Alcooleiros do Brasil'.

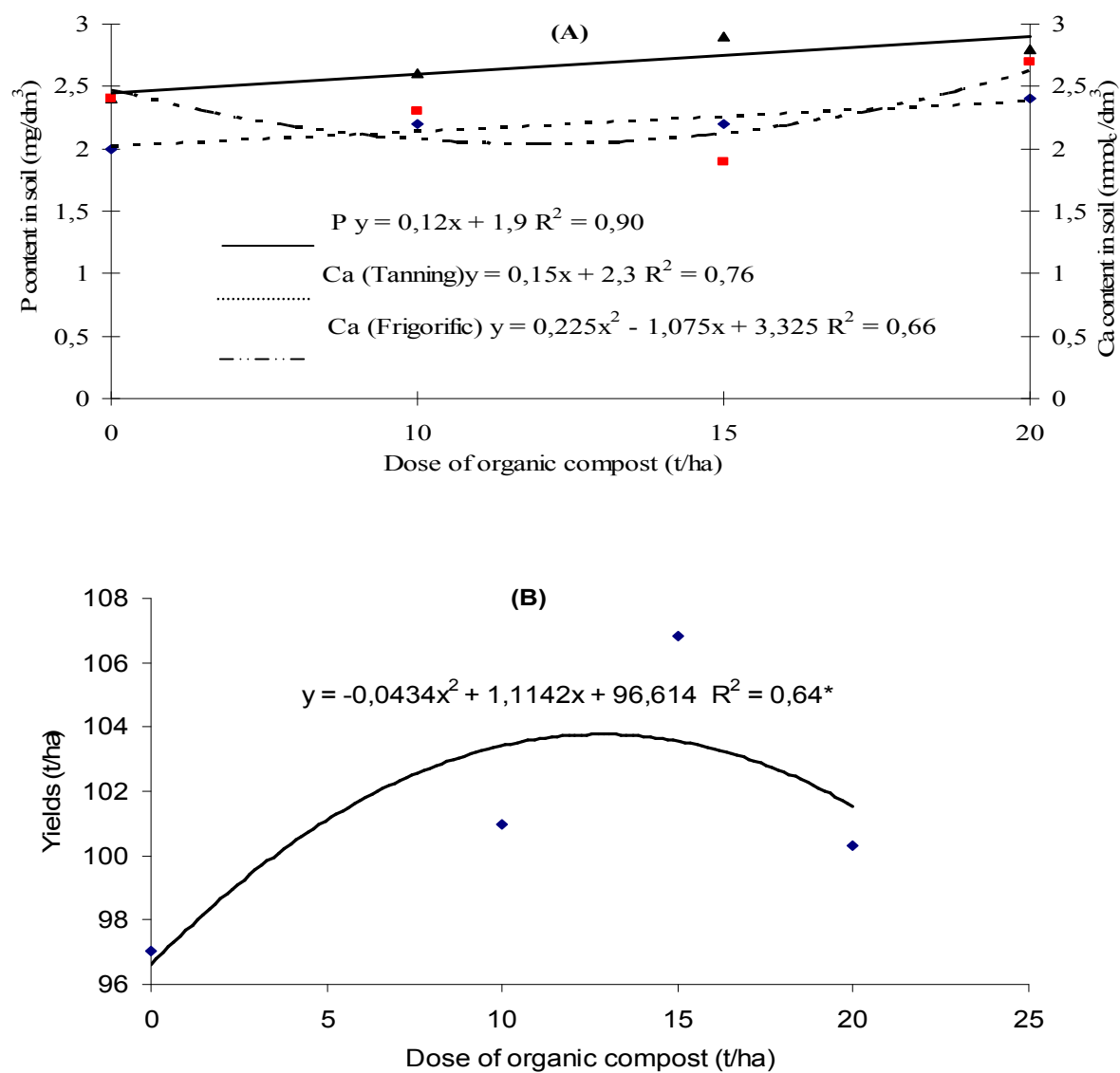


Figure 1. Average contents of phosphorus and calcium in the soil (A) and sugar cane yields (B) for doses of organic and mineral fertilizers. Agricultural year 2007/2008. Mineral fertilization with 275 kg/ha of 5:25:25.

Soil nitrification as affected by Brachiarias

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Abstract

The nitrification process in soil may result in substantial losses of applied nitrogen through nitrate leaching and N_2O emission to the atmosphere. Nitrification control could be a key strategy in improving nitrogen recovery and agronomic N-use efficiency. This study aimed to evaluate the ability of species of *Brachiaria* in inhibiting nitrification process in the soil. The treatments consisted of growing three pasture species (*Brachiaria brizantha*, *Brachiaria ruziziensis* and *Brachiaria decumbens*) fertilized with doses of nitrogen (0, 100, 200 and 300 mg/pot) plus a control (without plants). The experiment was carried out in a greenhouse in pots containing 10/dm³ of soil. In the absence of the brachiarias, soil NO_3^- increased with N rates. *B. ruziziensis*, when grown with 60 kg/ha of N, resulted in the lower soil nitrate concentration (an evidence of nitrification inhibition), but *B. decumbens* and *B. brizantha* had no effect on the nitrification process.

Introduction

The low use efficiency of nitrogen fertilizers and the potential pollution that comes from their losses are among the main concerns of agriculture. In soil, ammonium from fertilizers can be transformed in nitrate by nitrifying bacteria (Sousa and Lobato 2004). The nitrification of ammonium to nitrate actually is the transformation of a relatively immobile cation in a highly mobile anion that can result in losses by denitrification and/or leaching of NO_3^- (Subbarao *et al.* 2006). Thus, inhibition of nitrification may be a strategy to extend the time of residence of N in soil and improve the N use efficiency (Rodgers 1986). There is evidence of the occurrence of natural suppression of nitrification in some ecosystems, depending on the root exudation of some species (Subbarao *et al.* 2006). Tropical grasses, such as *Brachiaria humidicola*, release Braquialactona by the roots, which can reduce or even suppress nitrification in the rhizosphere soil (Subarao *et al.* 2009). In tropical environments, grasses of the genus *Brachiaria* are used as cover crops in no-tillage systems, so the objective of this study was to evaluate whether other species of *Brachiaria*, besides *B. humidicola*, used as cover crops in tropical agricultural systems, have the ability to inhibit nitrification in soil.

Material and Methods

The soil used in this experiment was collected from the surface layer (0-20 cm) of a typical Oxisol (EMBRAPA 1999), a sandy loam with pH 4.1, 18 g/dm³ of OM, 3.0 mg/dm³ of P_{resin} , 0.2, 2.0, 1.0 mmol/dm³ of K, Ca and Mg, respectively, 6.79 and 7.49 mg/kg of NH_4^+ and NO_3^- , respectively. Lime was applied to raise pH to 5.3 and P and K were applied at 150 mg/dm³, as superphosphate and potassium chloride. The experimental design was a randomized block with four replications in a factorial 4x4. The treatments were three grass species: *Brachiaria brizantha*, *Brachiaria decumbens* and *Brachiaria ruziziensis*, four N rates: 0, 100, 200 and 300 mg/pot, and a control without plants). At 14 days after planting, N rates of 0, 100, 200 and 300 mg/pot were applied as ammonium sulfate ($(NH_4)_2SO_4$). Forty days after nitrogen application plants shoots were cut close to the soil, washed, dried in a forced air oven for four days at 65 °C, ground and N (Bremner and Keeney 1966) was determined. After harvesting the plants, the soil of each pot was sampled and the rhizosphere soil was separated from bulk soil by gently shaking the root system, then the samples were dried and NH_4^+ and NO_3^- were determined by steam distillation (Bremner and Keeney 1966). The results were submitted to ANOVA and means were compared by t test (LSD, $P < 0.05$). Nitrogen effects were evaluated using regression analysis.

Results and Discussion

The increased availability of N resulted in a linear increase in dry matter yield of *B. decumbens* while in *B. brizantha* and *B. ruziziensis* dry matter yields showed quadratic responses, with maximums calculated at 248 and 297 mg/pot of N, respectively. In the absence of fertilizer, *B. decumbens* showed higher accumulation of N as compared with other brachiarias, due to its larger growth (Figure 1). However, with the supply of 200 and 300 mg/pot of N, *B. brizantha* and *B. decumbens* showed similar N uptake, and higher than that observed for *B. ruziziensis*. This shows that when N availability is a limiting factor, *B. ruziziensis* has a higher

efficiency of nutrient use. Applying N as ammonium led to small increases in the soil NH_4^+ level in the treatment without plants, and this treatment showed the lowest levels of NH_4^+ and higher concentrations of NO_3^- (Figure 2), showing that the activity of nitrifying bacteria was much higher without plants or the plants took up most of the nitrate transformed during plant growth.

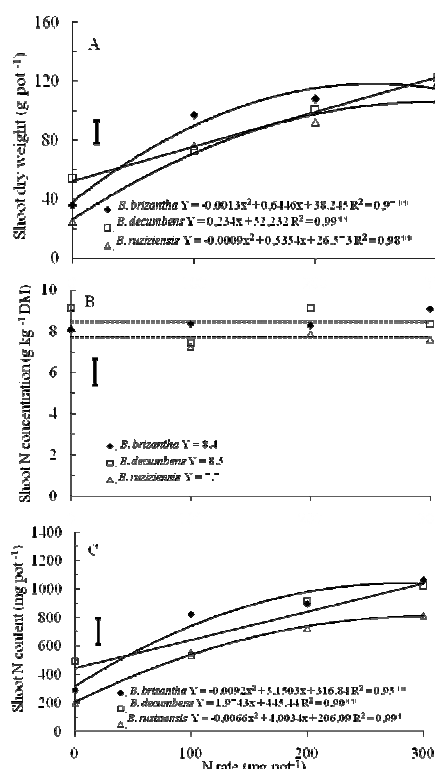


Figure 1. Shoot dry weight (A), N concentration (B) and N content (C) of pasture grasses as affected by N rates, 40 days after the application of nitrogen rate. * and ** significant at 5% and 1% probability by F test. Vertical bars indicate the value of the LSD ($P < 0.05$).

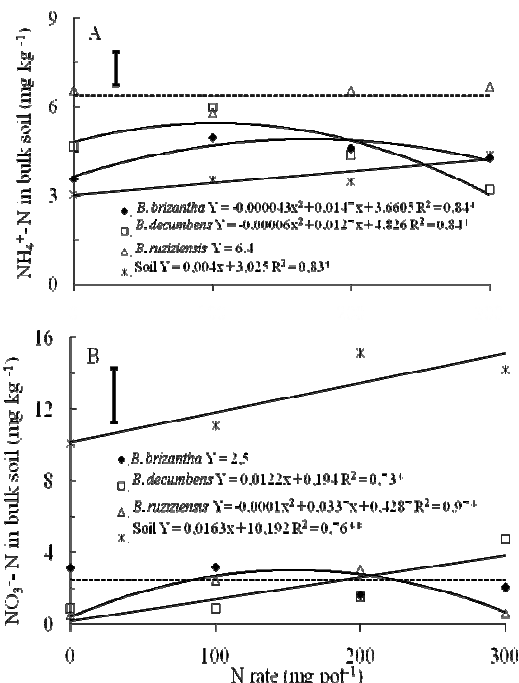


Figure 2. N - NH_4^+ (A) and N - NO_3^- (B) concentration in bulk soil of pasture grasses as affected by N rates, 40 days after the application of nitrogen rate. * and ** significant at 5% and 1% probability by F test. Vertical bars indicate the value of the LSD ($P < 0.05$).

Carmo *et al.* (2005), studying the N dynamics in soils with pastures and forests observed that with a mixture of *B. brizantha* and *P. maximum* soil N- NH_4^+ content was always greater than that of N- NO_3^- , 4.60 and 2.41 mg/kg, respectively, whereas in forest soil, the levels were similar for both nitrogen forms (4.83 for N- NH_4^+ and 4.21 mg/kg for N- NO_3^-). In the present experiment, the amount of NH_4^+ absorbed and/or nitrate content in the soil cropped to *B. ruziziensis* was lower than that obtained for the other forages, except for the treatment with 100 mg/pot of N (Figure 2), which is explained by the higher content of soil NH_4^+ at the end of the experiment in pots with this forage.

It was also observed that nitrification increased with N application, but there was no difference between the species as to N uptake (Figure 1c). In general, except for *B. ruziziensis*, soil NH_4^+ contents were lower than those observed in the rhizosphere (Figure 3). However, there were no differences between the NH_4^+ contents in the rhizosphere of the different species (Figure 3A). The lowest rhizosphere NO_3^- levels were observed under *B. brizantha* (Figure 3B). It can be inferred that NO_3^- uptake by this species created a gradient of concentration of N near the root surface, resulting in lower NO_3^- content in the rhizosphere. A second factor may have contributed to this low NO_3^- level, i.e., the reduction may be due an inhibitory effect of this species on biological nitrification. The results show that *B. decumbens* and *B. ruziziensis* do not inhibit the nitrification in the rhizosphere. Authors such as Sylvester-Bradley *et al.* (1988) and Ishikawa *et al.* (2003) also observed that *B. decumbens* do not inhibit nitrification as it has been reported for *B. humidicola*. Ishikawa *et al.* (2003) found that *B. humidicola* suppresses nitrification. They also observed that the suppression effect over the population of bacteria oxidizing ammonia lasted 12 days after the collection of plants, suggesting that the inhibition effect is long-lasting in the presence of plants in soil. The hypothesis of rhizosphere nitrification inhibition in this study is supported by the fact that no differences were found

between species on the amount of NH_4^+ absorbed and/or nitrified, on the amount of NO_3^- absorbed and between the total amounts of inorganic N absorbed per pot. Moreover, the relationship $\text{NH}_4^+/\text{NO}_3^-$ in the *B. brizantha* rhizosphere was greater than 15/1, while for *B. decumbens* and *B. ruziziensis* it was, respectively 3/1 and 1/1. This is evidence that there was at least some inhibitory effect of *B. brizantha* in the nitrification process, however, the effect was small and did not reflect on NH_4^+ and NO_3^- amounts in the bulk soil. In treatments that did not receive nitrogen fertilizer, 82%, 73% and 64% of total N absorbed by the species *B. decumbens*, *B. brizantha* and *B. ruziziensis* respectively, came from organic matter mineralization. When the higher N rate was applied, organic matter mineralization provided about 64% of the N absorbed by *B. brizantha* and *B. decumbens*, and 54% of the *B. ruziziensis* uptake. Subarao *et al.* (2007) observed that most of the soil inorganic N at the end of a 30-day incubation originated from the mineralization of organic N, which probably also occurred in this experiment.

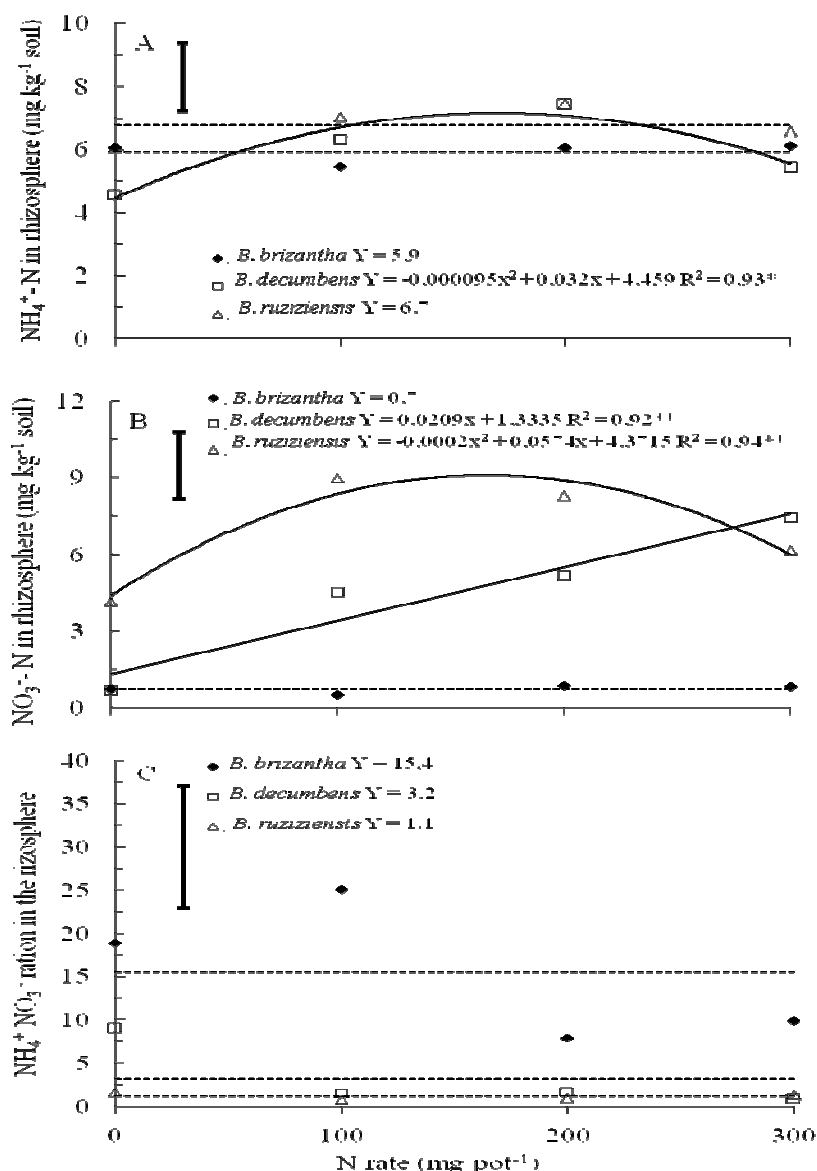


Figure 3. N- NH_4^+ (A), N- NO_3^- (B) concentration and ratio $\text{NH}_4^+/\text{NO}_3^-$ (C) in rhizosphere of pasture grasses as affected by N rates, 40 days after fertilization. * and ** significant at 5% and 1% probability by F test. Vertical bars indicate the value of the LSD ($P < 0.05$).

Conclusion

In this experiment, the mineralization of organic matter supplied much of the N taken up by the forage plants. *B. decumbens* and *B. ruziziensis* do not inhibit the nitrification in the rhizosphere, and the effect of *B. brizantha* on rhizosphere nitrification was not big enough to change NH_4^+ contents in bulk soil.

References

- Bremner JM, Keeney DR (1966) Determination and isotope-ratio analysis of different forms of nitrogen in soils: 3. Exchangeable ammonium, nitrate, and nitrite by extraction-distillation methods. *Soil Science Society of America Proceedings* **30**, 77-582.
- Carmo JB, Andrade CA, Cerri CC, Piccolo MC (2005) Disponibilidade de nitrogênio e fluxos de N₂O a partir de solo sob pastagem após aplicação de herbicida. *R. Bras. Ci. Sol.* **29**, 735-746.
- Embrapa – Empresa Brasileira de Pesquisa Agropecuária (1999) Sistema brasileiro de classificação de solos. Rio de Janeiro, Embrapa-Solos. 412p.
- Ishikawa T, Subbarao GV, Ito O, Okada K (2003) Suppression of nitrification and nitrous oxide emission by the tropical grass *Brachiaria humudicola*. *Plant and Soil* **255**, 413-419.
- Rodgers GA (1986) Nitrification inhibitors in agriculture. *Journal of Environmental Science and Health Part A* **21**, 701-722.
- Sousa DMG, Lobato E. (2004) Adubação com nitrogênio. In ‘Cerrado: correção do solo e adubação. Brasília, Embrapa Informação Tecnológica, 2004’. (Eds DMG Sousa, E Lobato) pp. 129-144.
- Subbarao GV, Ito O, Sahrawat KL, Berry WL, Nakahara K, Ishikawa T, Watanabe T, Suenaga K, Rondon M, Rao IM (2006) Scope and strategies for regulation of nitrification in agricultural systems-challenges and opportunities. *Critical Reviews in Plant Sciences* **25**, 303-335.
- Subbarao GV, Kakahara K., Hurtado MP, Ono HM, Oreta DE, Salcedo AF, Yoshihashi AT, Ishikawa T, Ishitani M., Ohnishi-Kaeyama M., Yoshida M., Rondon M., Rao IM, Lascano CE, Berry WL, Ito O. (2009) Evidence for biological nitrification inhibition in *Brachiaria* pastures. PNAS, doi/10.1073/pnas.0903694106.
- Subbarao GV, Rondon M., Ito O, Ishikawa T, Rao IM, Nakahara K, Lascano C, Berry WL (2007) Biological nitrification inhibition (BNI) – is it a widespread phenomenon? *Plant Soil* **294**, 5-18.
- Sylvester-Bradley R, Mosquera D, Mendez JE (1988) Inhibition of nitrate accumulation in tropical grassland soil: effect of nitrogen fertilization and soil disturbance. *J. Soil Sci.* **39**, 407-416.

Soil nutrition and common scab disease of potato in Australia

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Abstract

This research was conducted over 3 years in fields heavily infested with common scab (*Streptomyces scabies*) in Victoria, Australia. It is widely thought that high soil pH is the main driver of increased common scab expression. The four soil pH modifiers, hot lime, magnesium oxide, dolomite and gypsum, significantly increased soil pH, but the effect on common scab development appeared to be seasonal i.e. in some seasons, these amendments increased common scab, but in others they did not. Sulfur, which lowered soil pH, did not consistently reduce common scab. Our results suggest that pH alone may not be a driver for the development of common scab symptoms.

Key Words

Streptomyces scabies, soilborne diseases, *Solanum tuberosum*, plant disease suppression

Introduction

Common scab causes significant loss in yield and quality of potatoes worldwide. The disease symptoms are lesions on the surface of the mature tuber and these can vary widely, being raised, netted, shallow or deep-pitted. It is not clear what factors directly determine the nature of the scab symptoms, and different symptoms can be caused by strains of the same species (Loria *et al.* 1997). Infection of potato tubers is primarily through immature lenticels; therefore tubers are most susceptible to infection during the six week period of rapid tuber growth that commences when the tuber diameter reaches twice that of the stolon.

There are significant gaps in the knowledge of how soil factors such as nutrients influence disease. Understanding these relationships may help identify new disease reduction strategies. A number of soil macro- and micronutrients have been implicated in modifying disease severity (Lambert *et al.* 2005, Huber 1991). However, the specific impact of each factor on disease has not been clearly resolved. The availability of many soil nutrients is pH-dependent, and the most consistent factor associated with increased common scab incidence worldwide is increased soil pH.

In Australia, Lacey and Wilson (2001) found that common scab severity was related to soil pH combined with the concentration of exchangeable calcium (Ca), magnesium (Mg) and potassium (K) cations in Tasmanian ferrosol soils. The role of calcium in enhancing common scab disease has been extensively studied but the specific role of calcium is confounded by its effects on pH (Horsfall *et al.* 1954, Doyle and MacLean 1960; Lambert and Manzer 1991; Keinath and Loria 1989). Further, the concentration of soil calcium does not necessarily reflect the concentration in the tuber. Calcium plays many important roles in tuber physiology, including the regulation of stress-related factors caused by the environment and disease. Increased availability of manganese has been shown to reduce common scab in some trials but not in others (McGregor and Wilson 1964; 1966). Low pH soils tend to have higher levels of manganese. *Streptomyces* species are strong manganese oxidizers and all cultural conditions which lead to increased manganese availability lead to reduced common scab. However, manganese is quickly immobilised.

Soil characteristics greatly affect the severity of potato scab which is most severe in soils with pH 5.2-7.0. In some cases, scab control can be achieved by lowering the soil pH through the use of acidifying fertilizers or applications of sulfur, but generally pH values inhibitory to *S. scabies* are also unfavourable for potato root growth, thereby reducing yields. It has been demonstrated that calcium-based fertilizers such as agricultural lime and hot lime increase the incidence and severity of common scab, but whether this is a direct effect of pH on the pathogen or an indirect effect due to the influence of pH on other aspects of soil chemistry is unknown. High calcium levels in the absence of changes in pH may induce scab, and exchangeable calcium is reportedly a more reliable parameter than the soil pH (Davis *et al.* 1976; Goto 1985). Sulfur was the first nutrient to be used to control common scab and its suppressive effect was thought to be due to a reduction in soil pH. However, Davis *et al.* (1974) demonstrated reductions in common scab severity by the application

of sulfur and gypsum even though the treatments did not significantly reduce soil pH due to the highly buffered soil.

The research undertaken in this study aimed to identify nutrient-based fertilizers that reduce common scab in the field, and determine whether their activity is a direct effect on the pathogen, or an indirect effect that enhances the resistance of the potato plant.

Materials and methods

Replicated field trials were established at Cora Lynn, Victoria, Australia over 3 seasons with potato varieties (Simcoe in 2005/06, Denali in 2007/08, and Trent in 2008/09) which are susceptible to common scab. The natural pH of the soil was 5.2 in water. There were five soil treatments in 2005/2006 and eight in 2007/08 and 2008/09)

Table 12. Effects of soil treatments on incidence of common scab disease symptoms and total yield of tubers.

Treatment	Application time	Incidence of common scab (%)	Total tuber yield (t/ha)
2005/2006 Simcoe			
Untreated	Nil	20 ^b	26 ^b
Dolomite 5 t/ha	2 weeks prior to planting	22 ^b	27 ^b
Elemental S 1.5 t/ha	2 weeks prior to planting	15 ^{ab}	20 ^a
Hot lime 5 t/ha	2 weeks prior to planting	59 ^c	27 ^b
pH plus 125 L/ha	Tuber set	8.8 ^a	27 ^b
LSD P=0.05		9.5	3.5
2007/2008 Denali			
Untreated	Nil	37 ^{ab}	38
Dolomite 5 t/ha	2 weeks prior to planting	42 ^b	38
Hot lime 5 t/ha	2 weeks prior to planting	37 ^{ab}	38
pH plus 125 L/ha	Tuber set	23 ^{ab}	39
Magnesium oxide 5 t/ha	2 weeks prior to planting	35 ^b	36
Potash 100 kg/ha	2 weeks prior to planting	37 ^{ab}	40
Epsom salts 40 kg/ha	2 weeks prior to planting	30 ^{ab}	40
Gypsum 5 t/ha	2 weeks prior to planting	28 ^a	39
LSD P=0.05		14.5	ns
2008/2009 Trent			
Untreated	Nil	86	19
Elemental S 1.5 t/ha	2 weeks prior to planting	73	19
Hot lime 1 t/ha	2 weeks prior to planting	88	18
pH plus 125 L/ha	Tuber set	90	18
Magnesium oxide 5 t/ha	2 weeks prior to planting	89	17
Epsom salts 168 kg/ha	2 weeks prior to planting	83	19
MnSO ₄ 168 kg/ha	2 weeks prior to planting	89	19
Hot lime 1 t/ha & Epsom 168 kg/ha	2 weeks prior to planting	88	20
LSD P=0.05		ns	ns

The following measurements were made during the season: 8 weeks after planting plots were assessed for plant emergence and height; at harvest tubers were assessed for disease incidence and severity, total and marketable yield. In 2007/2008 and 2008/2009 soil was collected at tuber set and plant petioles prior to senescence for determination of nutrient status.

Results

Season 2005/2006 Simcoe

At 8 weeks after planting there was no significant difference between treatments for plant emergence and height. At harvest, common scab severity was significantly reduced by pH plus, but significantly increased by the application of hot lime (Table 12). Total yield was significantly reduced by elemental sulfur.

Season 2007/2008 Denali

Some of the treatments significantly altered the nutrient status of the soil at tuberset and affected nutrient uptake into the potato plant (Table 13). None of the treatments reduced soil pH. Dolomite increased symptoms compared to the untreated control (Table 12). Both hot lime and gypsum significantly increased soil pH but this did not lead to elevated levels of common scab. Gypsum and Epsom salts significantly increased ($P < 0.04$) marketable yield.

Table 13 Summary of treatment effects on soil nutrient status and of plant parts 2007/2008 (Denali) and 2008/2009 (Trent).

	2007/2008 Denali			2008/2009	Trent
Treatment	Soil nutrient status	Petiole nutrient status	Peel nutrient status	Petiole nutrient status	Peel nutrient status
Dolomite	↑Cu		↑Cu		
Epsom		↓Cu			↑Co P
Gypsum	↑pH Ca Cu Mn S	↑S Co	↑S Cu ↓Na		
Hot lime	↓%H Al K:Mg ↑ Ca Mg	↓Mn	↑S Cu	↓Mn	↑Ca Mg P
MgO	↓%H K:Mg ↑Mg pH	↓Mn Cu Co		↓ Mn	↑ Mg P ↓ Ca
Potash		↓ Cu			
Hot lime & Epsom				↑Na ↓ Mn	↑ Ca Mg P
MnSO4				↑ Mn	↑Mn ↓ Ca Mg
Sulfur					↑S Co ↓Ca

Season 2008/2009 Trent

Several treatments significantly altered the nutrient status of the soil and uptake into the plant (Table 12, Table 13). Although several treatments modified the concentrations of calcium, manganese and sulphur in plant tissues, this did not alter disease levels on tubers at harvest. None of the treatments had an effect on common scab, total or marketable yield and specific gravity (Table 12). The overall level of common scab disease was very high on this susceptible variety.

Discussion

It is widely thought that soil pH is the main driver of common scab expression, with high pH increasing the incidence of common scab. The soil pH modifiers hot lime, magnesium oxide, dolomite and gypsum significantly increased soil pH, but the effect on common scab development appeared to be seasonal i.e. in some seasons, these amendments increased common scab, but in others they did not. Sulfur, which lowered soil pH, did not consistently reduce common scab. Our results suggest that pH alone may not be a driver for common scab symptom development.

In some seasons, gypsum and hot lime increased soil calcium but did not increase disease incidence on tubers. Different forms of calcium affected common scab disease expression differently, impacting on disease severity rather than incidence. In glasshouse studies, addition of 1 t/ha of hot lime increased soil calcium without increasing the severity of common scab on tubers (Wiechel *et al.* 2007). This would allow growers the option to apply small amounts of lime to increase soil pH without fear of exacerbating common scab symptoms.

Manganese has been linked to a reduction in common scab in some trials but not in others (McGregor and Wilson 1966). In our trials, however, elevated soil and plant manganese levels were not associated with a reduction in common scab. Low pH soils tend to have higher levels of manganese. The soils in this trial were

pH 5.2, so the amount of manganese available may have already been high and any additions leached out. Lack of control of common scab in some seasons may have been due to the timing of application resulting in less optimal rates and possible leaching of nutrients during the interval between application and tuberset, the time when tubers are the most susceptible to infection. The research showed that nutrient amendments were taken up by the plant into the petiole and peel, but this did not translate into reduced disease symptoms.

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References

- Davis JR, Garner JG, Callihan RH (1974) Effects of gypsum, sulfur, terraclor and terraclor super-x for potato scab control. *American Potato Journal* **51**, 35-43.
- Davis JR, McDole RE, Callihan RH (1976) Fertilizer effects on common scab of potato and the relation of calcium and phosphate-phosphorus. *Phytopathology* **66**, 1236-1241.
- Doyle JJ, MacLean AA (1960) Relationships between C:K ratio, pH and prevalence of potato scab. *Canadian Journal of Plant Science* **40**, 616-619.
- Goto K (1985) Relationships between soil pH, available calcium and prevalence of potato scab. *Soil Science and Plant Nutrition* **31**, 411-418.
- Horsfall JG, Hollis JP, Jacobson HGM (1954) Calcium and potato scab. *Phytopathology* **44**, 19-24.
- Huber DM (1991) The use of fertilizers and organic amendments in the control of plant disease. In 'Handbook of Pest Management in Agriculture'. (Ed. Pimental D), pp. 405-494. (CRC Press: Boca Raton, Florida).
- Keinath AP, Loria R (1989) Management of common scab of potato with plant nutrients. In 'Soilborne Plant Pathogens: Management of Disease with Macro- and Microelements', pp. 152-166. (American Phytopathological Society: St Paul).
- Lacey MJ, Wilson CR (2001) Relationship of common scab incidence of potatoes grown in Tasmanian ferrosol soils with pH, exchangeable cations and other chemical properties of those soils. *Journal of Phytopathology* **149**, 679-683.
- Lambert DH, Manzer FE (1991) Relationship of calcium to potato scab. *Phytopathology* **81**, 632-636.
- Lambert DH, Powelson ML, Stevenson WR (2005) Nutrition interactions influencing diseases of potato. *American Journal of Potato Research* **82**, 309-319.
- Loria R, Bukhalid RA, Fry BA, King RR (1997) Plant pathogenicity in the genus *Streptomyces*. *Plant Disease* **81**, 836-846.
- McGregor AJ, Wilson GCS (1964) The effect of applications of manganese sulphate to a neutral soil upon the yield of tubers and the incidence of common scab in potatoes. *Plant and Soil* **20**, 59-64.
- McGregor AJ, Wilson GCS (1966) The influence of manganese on the development of potato scab. *Plant and Soil* **25**, 3-16.
- Wiechel TJ, Donald EC, Crump NS (2007) Effect of calcium compounds on common scab of potato. *Proceedings of the 16th Biennial Australasian Plant Pathology Conference Adelaide, Australia*.

Soil phosphorus distribution in a crop production system with long-term compost amendment

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Abstract

Excessive fertilization with inorganic or organic phosphorus (P) amendments, such as compost, increases the risk of P losses to surface waters. To properly manage fertilizer amendments, an understanding of P distribution in soil is essential. The objective of this research was to evaluate P distribution in soil with and without long-term compost amendment in a maize (*Zea mays* L.)-soybean (*Glycine max* L. Merr.)-wheat (*Triticum aestivum* L.)/clover (*Trifolium repens* L.) crop rotation managed with moldboard plow (MP), chisel plow (CT), or no-tillage (NT), with all phases present each year since 1988. Soil (Clarion silt loam and Canisteo silty clay loam) samples were collected in 2007 from three depth increments (0-7.5; 7.5-15; 15-30 cm) of each plot. Water-extractable P, Bray-1 extractable P, total P, and degree of P saturation (DPS) were determined from subsamples. Long-term compost application increased all P forms in the soil profile. The low C:P ratio of the compost likely increased soil P mineralization, leading to the differences we measured. The intensity of tillage affected all measures of P in the surface soil more than the crop that was grown. Water-extractable P was higher in the CT and NT treatments relative to the MP treatment, and tended to be higher following soybean. Similar results were found for Bray 1 P and total P. Compost applications can increase soil P, mainly P forms most susceptible to losses, thereby increasing the risk of P losses by leaching and runoff. Conservation tillage can reduce P leaching by keeping P in topsoil layers where root activity is higher. To decrease the risk of P losses from these cropping systems, compost applications should be P based.

Key Words

Soil phosphorus, water quality, compost amendment.

Introduction

Tillage practices and soil amendments play an important role in P dynamics and distribution in the soil profile. Conservation tillage systems tend to concentrate plant-available P in topsoil layers where root activity is higher. Application of organic amendments, such as compost, to cropland increases soil organic carbon, as well as the content of P and other plant nutrients. Thus, compost amendments can be an economical alternative for P supply to crops, given the high cost of inorganic P sources and the large amount of organic material available to use as fertilizer in areas near animal production. The beneficial influence of long-term compost applications on the physical, chemical, biochemical, and microbiological properties of soils and crop yields has been well documented (Singer *et al.* 2004, 2007, and 2008). Singer *et al.* (2008) found that compost applications may eliminate yield differences between conventional and minimum tillage. On the other hand, when compost application supplies P that exceeds crop removal, P levels will build in topsoil (Sharpley 1996; Lehmann *et al.* 2005). Phosphorus removals depend on the crop that is grown, and whether grain and/or biomass are harvested (Johnson *et al.* 2009). If soil P levels are allowed to build, the risk of P losses to ground and surface water increases as soil P sorption capacity approaches saturation (Novak *et al.* 2000; Schoumans and Groenendijk 2000). Although the amount of P lost per year in runoff is generally inconsequential from an agronomic perspective, small increases in P concentration in surface water often result in eutrophication of water bodies (Hart *et al.* 2004).

To complement agronomic soil tests, several methods have been devised to assess the risk of P loss from soil to surface water. The degree of P saturation (DPS) is an environmental index that has been used to assess the potential for P release to runoff and leaching (Zhou and Li 2001). Several studies have reported highly

significant correlation of DPS with the forms of P most susceptible to runoff and leaching losses (Pote *et al.* 1996, Pote *et al.* 1999, Ige *et al.* 2005). The objective of this research was to evaluate: i) the distribution of added P among various P forms in soil following long-term compost application associated with tillage-cropping systems; and ii) the relationship of various P forms with potential P losses by leaching and runoff.

Methods

The soil for the study was collected from research plots at the Iowa State University Agronomy and Agricultural Engineering Research Farm near Ames, Iowa, USA. The soils were classified as Canisteo silty clay loam (fine-loamy, mixed, superactive, calcareous, mesic Typic Endoaquolls) and Clarion loam (fine-loamy, mixed, superactive, mesic Typic Hapludolls). The experimental site had been in continuous maize production since 1987, with tillage main plots consisting of moldboard plow (MP), chisel plow (CT), and no-till (NT) since 1988. In 1997, the entire site was planted to soybean. In 1998, a maize–soybean–wheat/clover rotation was initiated with all phases represented each year in each tillage system. Additional information about the management practices can be found in Singer *et al.* (2004) and Singer *et al.* (2010). During the first six years of the study (1998–2003), an average of 6000 kg C/ha/yr were applied via compost. Although compost application rates changed to a P removal basis in 2004, an average of 157 kg P/ha/yr were applied since 1998. On average, the C:N ratio of the compost was 13.9, and the C:P ratio was 33.5. The experimental design was a randomized complete block in a split-plot treatment arrangement with four replicates. Plots were 22.8 m wide by 26.1 m long. Fall moldboard plow depth prior to maize and soybean crops was approximately 20 cm. Fall chisel plow depth, using twisted shanks, was approximately 25 cm for the same crops. Spring secondary tillage operations prior to maize and soybean included an early spring disking and a pre-plant field cultivation in MP and CT systems. Subplots, 7.6 m (10 rows with a 0.76-m row spacing) wide by 13.1 m long, consisted of fall-applied compost or no compost.

Representative soil samples were collected periodically to a depth of 18 cm during the first nine years of the study, and analyzed for Bray-1 extractable P. To better characterize nutrient levels in the surface soil, samples were collected in 2007 from three depth increments (0–7.5; 7.5–15 and 15–30 cm) of each plot. All soils were air dried, sieved (2 mm), and stored at 23°C prior to analysis. For the soil surface layer (0–7.5 cm), water-extractable P, Bray-1 extractable P, total P, and degree of P saturation ($DPS = (\text{extractable P/P sorption index}) \times 100$) were determined. For the subsoil layers, only Bray-1 extractable P was determined. Analysis of variance (ANOVA) was used to evaluate differences in the distribution of P in the soil profile as affected by compost application and tillage-crop rotation.

Results and Discussion

The compost P applied during the first nine years of the study increased Bray-1 extractable P in the top 18 cm of the profile to levels well in excess of crop needs (Figure 1a). Tillage had little effect on Bray-1 P until 2006 when mean values in the CT and NT treatments were 50% higher than those in the MP treatments. The high values observed with compost-amended soils may be due to the low compost C:P ratio, which can increase P mineralization. Similar results were reported by Motavalli and Miles (2002) in a study of soil P fractions after 111 years of animal manure and fertilizer applications, as well as by Eghball (2003) in a study of P leaching following manure or compost application. Generally, the P in the compost used in our work is 70% inorganic, which is readily available for plant absorption, microbial turnover, and soil adsorption. In the last case, when the P sorption capacity reaches saturation, P can be lost by leaching or surface runoff, if the amounts applied exceed crop removal.

When compared with subsoil layers, the topsoil had the highest P levels with or without compost application (Figure 1b). Compost application, however, increased soil profile P to a depth of 30 cm. This suggests that surface soil P levels increased sufficiently to allow P to move into the profile when compost was applied. There was less subsoil P in the NT system compared with the MP and CT systems. Almost 50% of the P applied with the compost was found in the subsoil layers under the MP system. The distribution of P in the soil profile is an important aspect to consider in areas with shallow groundwater or a fluctuating water table that moves close to the soil surface (Eghball 2003).

When compost was applied, WEP, Bray-1 P, total P, and DPS increased in the topsoil (0–7.5 cm) layer (Table 1) regardless of crop or tillage system. The intensity of tillage affected all measures of P in the surface soil more than the crop that was grown. Water-extractable P was higher in the CT and NT treatments relative to the MP treatment, and tended to be higher when soybean was grown (Table 1). Similar results were found

for Bray 1 P and total P, and suggest that soybean harvest removed less P from the surface soil than was removed by the maize and wheat harvests. Several authors have reported a significant correlation between dissolved reactive P concentration in surface runoff and WEP (Pote *et al.* 1996, Pote *et al.* 1999), indicating that WEP can be used as an index of soil P that is readily lost to runoff. In addition, mean DPS under NT was the highest value observed. As the DPS increases, the capacity of the soil to retain P decreases, suggesting that the NT treatment posed the greatest risk of P losses by either leaching into soil profile and/or surface runoff. On the other hand, conservation tillage maintains cover on the soil surface, reducing raindrop impact and subsequent soil erosion. No-till can also increase soil aggregation, and consequently soil water infiltration, which can reduce erosion and soil P losses with runoff. Tillage will mix the compost P into the profile (Sharpley 2003); however, the increases in WEP and the reduction of soil P sorption capacity with time must be considered.

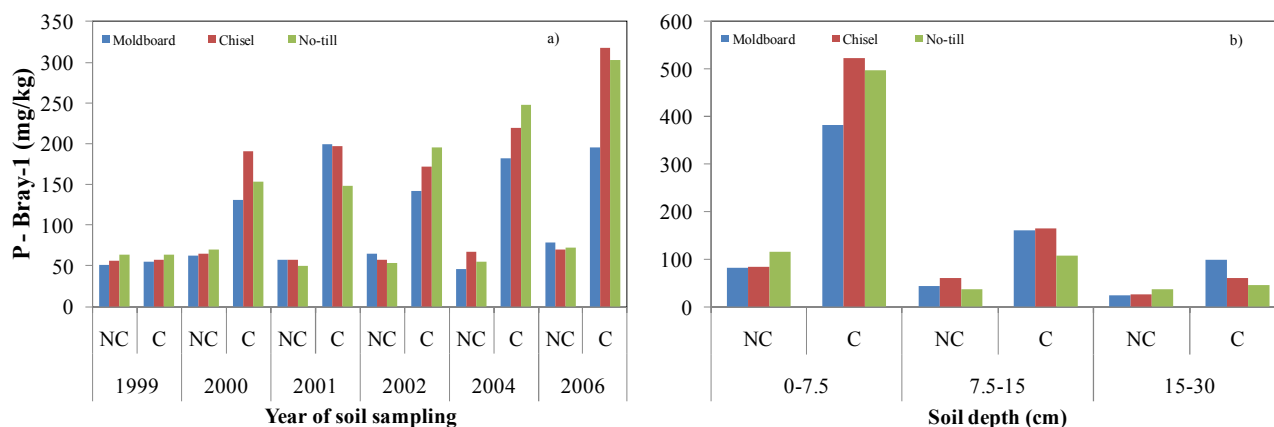


Figure 1. Soil phosphorus extractable with Bray-1 during a 9-year period in a crop production system with long-term compost amendment: (a) 0-18 cm soil depth and (b) soil profile sampled within 3 soil depths in fall 2007. Optimum Bray-1 P range is 16-20 mg/kg. NC=no compost; C=compost application.

Table 1. Water extractable P (WEP), Bray-1 extractable P (Bray-1), total P (Total), and degree of P saturation (DPS) as affected by tillage, compost application, and cropping system in the top soil layer (0-7.5 cm).

Factor	Soil P							
	WEP		Bray-1		Total		DPS	
	----- mg/kg -----							
Moldboard	C [†]	NC [‡]	C	NC	C	NC	C	NC
Bean	7.4	1.7	373	83	860	682	53	12
Maize	8.2	2.4	408	88	908	676	61	13
Wheat	7.6	1.7	366	74	843	721	54	11
Mean	7.7	1.9	382	82	870	693	56	12
Chisel								
Bean	12.9	4.5	523	96	1059	772	79	14
Maize	11.1	2.5	494	65	973	660	74	12
Wheat	11.1	3.0	477	93	955	711	71	14
Mean	11.7	3.3	498	85	996	714	75	13
No-till								
Bean	17.0	3.4	612	106	1222	795	91	16
Maize	10.6	3.1	477	120	1153	772	72	18
Wheat	9.7	2.8	482	119	967	701	72	18
Mean	12.4	3.1	523	115	1114	756	79	17
ANOVA	-----		P > F		-----			
Amendment	<0.01		<0.01		<0.01		<0.01	
Tillage	0.03		0.04		0.02		0.04	
Am x Till	0.90		0.86		0.23		0.80	
Crop	0.07		0.05		<0.01		0.06	
Am x crop	0.38		0.21		0.02		0.32	
Till x crop	0.18		0.25		<0.01		0.41	
Am x Till x crop	0.32		0.33		0.67		0.57	

[†] Compost; [‡] No compost

Conclusion

Long-term compost applications can build up soil P, mainly the forms most susceptible to losses, so that the risk of P losses by leaching and runoff increases. Conservation tillage practices can reduce P leaching and keep P in topsoil layers where root activity is more concentrated. This promotes P cycling in the soil-plant system, but may increase the risk of P losses in surface runoff. Intensive tillage will mix applied P into the profile, but increases WEP and reduces soil P sorption capacity with time, which poses a threat to groundwater, even though lower P levels in surface soil decrease P losses in runoff. To decrease the risk of P losses from these cropping systems, compost applications should be P based.

References

- Eghball E (2003) Leaching of Phosphorus Fractions Following Manure or Compost Application. *Communications in Soil Science and Plant Analysis* **34**, 2803-2815.
- Hart MR, Quin BF, Nguyen ML (2004) Phosphorus runoff from agricultural land and direct fertilizer effects: a review. *Journal of Environmental Quality* **33**, 1954-1972.
- Ige DV, Akinremi OO, Flaten, DN (2005) Environmental index for estimating the risk of phosphorus loss in calcareous soils of Manitoba. *Journal of Environmental Quality* **34**, 1944-1951.
- Lehmann J, Lan Z, Hyland C, Sato S, Solomon D, Ketterings QM (2005) Long-term dynamics of phosphorus forms and retention in manure-amended soils. *Environmental Science Technology* **39**, 6672-6680.
- Motavalli PP, Miles RJ (2002) Soil phosphorus fractions after 111 years of animal manure and fertilizer applications. *Biology and Fertility of Soils* **36**, 35-42.
- Novak JM, Watts DW, Hunt PG, Stone KC (2000) Phosphorus movement through a Coastal Plain soil after a decade of intensive swine manure application. *Journal of Environmental Quality* **29**, 1310-1315.
- Pote DH, Daniel TC, Nichols DJ, Sharpley AN, Moore PA, Miller DM, Edwards DR (1999) Relationship between phosphorus levels in three Ultisols and phosphorus concentrations in runoff. *Journal of Environmental Quality* **28**, 170-175.
- Pote DH, Daniel TC, Sharpley AN, Moore PA, Edwards DR, Nichols DJ (1996) Relating extractable soil phosphorus to phosphorus losses in runoff. *Soil Science Society of America Journal* **60**, 855-859.
- Schoumans OF, Groenendijk P (2000) Modeling soil phosphorus levels and phosphorus leaching from agricultural land in the Netherlands. *Journal of Environmental Quality* **29**, 111-116.
- Sharpley AN (2003) Soil mixing to decrease surface stratification of phosphorus in manured soils. *Journal of Environmental Quality* **32**, 1375-1384.
- Sharpley AN (1996) Availability of residual phosphorus in manured soils. *Soil Science Society of America Journal* **60**, 1459-1466.
- Singer JW, Kohler KA, Liebman M, Richard TL, Cambardella CA, Buhler DD (2004) Tillage and compost affect yield of corn, soybean and Wheat and Soil Fertility. *Agronomy Journal* **96**, 531-537.
- Singer JW, Logsdon SD, Meek DW (2007) Tillage and compost effects on corn growth, nutrient uptake, and grain yield. *Agronomy Journal* **99**, 80-87.
- Singer JW, Logsdon SD, Meek DW (2008) Soybean growth and seed yield response to tillage and compost. *Agronomy Journal* **100**, 1039-1046.
- Singer JW, Chase CA, Kohler KA (2010) Profitability of cropping systems featuring tillage and compost. *Agronomy Journal* **102**, (in press).
- Zhou M, Li Y (2001) Phosphorus-sorption characteristics of soils and limestone from the Southern Everglades and adjacent farmlands. *Soil Science Society of America Journal* **65**, 1404-1412.

Soil properties under *Orthosiphon stamineus* (Benth) intercropped with *Durio zibethinus* (Murr) and treated with various organic fertilizers

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Abstract

Orthosiphon stamineus (Benth) is a herb that can be intercropped under shade trees. There is a lack of information the soil properties for *O. stamineus* intercropped with durian. In this study, the soil was tested to determine nutrient levels with respect to the organic fertilizer treatments such as chicken dung, cow dung and oil palm empty fruit bunch (EFB). The study was carried out in the fields of smallholder's rubber at Papar, Sabah. The soil series of this area belongs to Inanam family (Gleyic Acrisol) as it is characterized with a gleyic horizon. The objective of this study was to determine the physico-chemical soil properties growing *O. stamineus* for the various fertilizer application regimes. The field planting distance used was 1.5 m x 0.45 m. Higher rate of fertilizer application gave higher yields of *O. stamineus*. Chicken dung was the best fertilizer followed by oil palm EFB and cow dung. The productivity using oil palm EFB and cow dung was smaller compared to chicken dung. Soil physical properties did not show any influence on the growth and yield of *O. stamineus*. However, the soil chemical properties influenced growth and were dependent on the type of fertilizer applied.

Key Words

Intercropping, organic fertilizer, soil physical and soil chemical properties.

Introduction

There is a lack of information about the soil properties for *O. stamineus* intercropped with durian. In this study, the soil was tested to determine the nutrient levels with respect to the organic fertilizer treatments. Previously, Affendy (2009) found that the best rate of fertilizer that can be applied was 0.9 kg per plant of *O. stamineus* intercropped with durian compared to 0.6 kg per plant. With this rate of fertilizer, the yield (dry matter) of *O. stamineus* intercropped with durian using chicken dung, cow dung, oil palm empty fruit bunch (EFB) and control (without fertilizer) were 253, 43, 56 and 31 kg/ha respectively.

Materials and Methods

Soil Sampling and Analysis

In this study, soil samples were taken before and after fertilizer application for each treatment at soil depths 0-5cm, 5-15cm and 15-30cm. One block contained 12 samples resulting in 144 samples in total. The samples were taken three times at month 0 (before fertilizer application), month 6 (after six months of the first fertilization) and month 12 (after second fertilization). Soil samples were air-dried at room temperature (Carter 1993; Tan 2005). The samples were then analyzed for physical and chemical properties. The soil physical properties were soil texture and soil moisture (% MC). Soil texture was determined by the pipette method (dispersion, sedimentation and decantation), while soil moisture content was determined by gravimetric method which involves the measurement of water lost after it is dried at 105-110°C (Tan 2005). Soil chemical properties included pH using 1:2.5 soil:water solution by a pH meter (Bantex, Digital pH meter, A 300), total nitrogen (N), available phosphorus (P), available potassium (K), magnesium (Mg) and calcium (Ca). The total nitrogen in soil was determined using the block digester technique (QuickChem, Method 13-107-06-2-D) as detailed by David (2001). Available phosphorus was determined by the Mehlich 3 method (1984) as detailed in Carter (1993). Exchangeable K, Mg and Ca in the soil were also determined by Mehlich 3 method (Mehlich 1984).

Statistical Analyses

The data were subjected to one-way Analysis of Variance (ANOVA), for soil physical properties under durian, two-way ANOVA for soil chemical properties for different organic fertilizer treatments.

Results and Discussion

Soil Physical Properties

Table 1 shows the results of physical properties (% MC, temperature, % sand, % silt and % clay) of 3 soil depths in the durian with *O. stamineus* intercropping system. The results show that the mean values for soil moisture increase with depth. This is because the topsoil is subject to more evaporation. The lower moisture content of the topsoil can be attributed to a greater exposure of the topsoil to direct radiation from the sun which can increase the soil temperature and the evaporation of water (Soo 1990). Nardi *et al.* (2006) found that *Artemisia rothrockii* or also called Sagebrush (Herbaceous meadow) used deeper water on average than most herbs, but it also acquired 10-30% of its water from shallow (< 30cm) soil. Also the higher soil temperature as shown in the results for the topsoil will result in higher evaporation. The results are similar to those of Zahari (2005). The soil had a high percentage of sand. According to Tan (2005), when sand is dominant, the soil exhibits coarse or light textures which are loose and friable and easy to plow.

Table 1 Physical properties for 3 soil depths for the *O. stamineus* and durian intercrop

Property	Depth (cm)	Mean ^A
MC (%)	0-5	0.30 ^c
	5-15	0.40 ^b
	15-30	0.54 ^a
Temperature (°C)	0-5	27.4 ^a
	5-15	26.9 ^b
	15-30	26.3 ^c
Clay (%)	0-5	21.8 ^{ns}
	5-15	21.4 ^{ns}
	15-30	23.1 ^{ns}
Silt (%)	0-5	12.2 ^{ns}
	5-15	11.6 ^{ns}
	15-30	11.7 ^{ns}
Sand (%)	0-5	66.0 ^{ns}
	5-15	67.0 ^{ns}
	15-30	65.3 ^{ns}

^AMean values with different letters were significantly different at 5% level probability ($p < 0.05$) using ANOVA and DMRT (ns= not significant).

Soil Chemical Properties

Table 2 shows the results of chemical properties for the soil on which is growing durian and *O. stamineus* for the four fertilizer treatments. There were no significant differences between the fertilizer treatments for total N at 5% level ($p > 0.05$). However, there were significant differences for available P, exchangeable K, Mg, Ca and CEC at 5% level ($p < 0.05$).

For available P, the chicken dung contained the highest available P which was 37%, 6.1% and 88.4% more than cow dung, oil palm EFB and control respectively. For exchangeable K, the chicken dung contained the highest exchangeable K which was 60%, 61.3% and 88.9% more than cow dung, oil palm EFB and control respectively. For exchangeable Mg, the chicken dung contained the highest exchangeable Mg which was 15%, 6.1% and 31.8% more than cow dung, oil palm EFB and control respectively. However, for exchangeable Ca, the cow dung contained the highest exchangeable Ca which was 8.8%, 8% and 55% more than chicken dung, oil palm EFB and control respectively. For CEC, the chicken dung had the highest CEC which was 20.1%, 21% and 57% more than cow dung, oil palm EFB and control respectively.

Table 2. Chemical properties of soils sampled from the *O. stamineus* - durian intercrop system for the different fertilizer treatments

Treatments	Property ^A					
	Total N %	Available P (----- mg/kg -----)	Exc. K mg/kg	Exc. Mg	Exc. Ca	CEC cmol/kg
Chicken dung	0.11 ^{ns}	132.9 ^a	257.7 ^a	77.8 ^a	154.9 ^a	20.8 ^a
Cow dung	0.12 ^{ns}	83.8 ^b	102.9 ^b	66.1 ^c	169.8 ^a	16.6 ^b
Oil Palm EFB	0.10 ^{ns}	124.8 ^a	99.7 ^b	72.9 ^b	156.3 ^a	16.5 ^b
Control	0.10 ^{ns}	15.4 ^c	28.6 ^c	53.1 ^d	77.0 ^b	9.0 ^c

^AMean values with different letters were significantly different at 5% level probability, $p < 0.05$ using ANOVA and DMRT (ns= not significant).

Generally, the soil N in the present study was low compared to soil N under *Eurycoma longifolia* in natural forest which ranged between 0.18 to 0.27% (Zahari 2005). This is because the roots of *O. stamineus* compete with roots of rubber or durian to absorb the nutrients and water. Furthermore, in natural forests the soil is rich in soil organic matter. According to Zahari (2005), the soil P of natural forest growing *Eurycoma longifolia* ranged from 104.61 to 170.69 mg/kg. Affendy (2005) found that soil P under *Azadirachta excelsa* was 152.4 mg/kg at Pasoh Forest Reserve, Negeri Sembilan. It can be concluded that the available P in this study area was comparatively higher if substantial fertilizer is applied compared to the results of previous studies. For exchangeable K, the results are in agreement with a previous study done by Yusop (2003) who found that the exchangeable K concentration was 326.69 mg/kg for samples from Pasoh Forest Reserve, Negeri Sembilan. The lower K concentration might be due to the characteristics of K as it is highly mobile and easily leached (Liu and Bates 1990). Furthermore, K is a monovalent cation while Ca and Mg are divalent. Therefore, the bond or force of attraction between K and soil micelle is weaker, and so the cation is much more susceptible to leaching than the exchangeable Ca and Mg (Olowolafe 2008). The higher soil K in the chicken dung treatment is due to higher potash in chicken dung.

In terms of soil Mg, the higher values were only for chicken dung and oil palm EFB with slow release characteristics. Affendy (2005) found that soil Mg under indigenous species ranged from 317.49 to 799.92 mg/kg. The indication of higher content might be partly due to the presence of organic matter and the sedimentary nature of the soil. The low content could be due to rapid leaching as a result of magnesium release from weathering (Shao 1979). Azani (1998) also reported that indigenous tree species in a planting area accumulate high Ca concentration in the soil. In contrast, Affendy (2005) and Zahari (2005) found that soil Ca was lower ranging between 32.34 to 60.05 mg/kg and 51.32 to 60.12 mg/kg respectively.

For CEC, Zahari (2005) found that the CEC of soil on which growing *Eurycoma longifolia* under natural forest was lower ranging from 7.20 to 7.47 cmol⁺/kg. The reason might be due to the difference in forest types and the fertilizers used in the present study. Furthermore, a previous study by Olowolafe (2008) reported that the exchangeable bases have their highest values in the surface horizons, and then somewhat decrease down the profiles, particularly in the soils to which town waste has been applied and organic fertilizer as used in the present study.

The higher N concentrations in the present study affected the yield of *O. stamineus* especially under chicken dung (0.11 – 0.12%). This is in agreement with a previous study which showed that the height growth and leaf number production of rattan manau seedlings are affected when the seedlings are deficient in nitrogen (Raja Barizan and Aminuddin 1992).

Conclusion

In conclusion, soil physical properties do not show any influence to the growth of *O. stamineus*. The soil type for both sites was sandy clay loam which is suitable to the *O. stamineus*. However, the soil chemical properties influenced growth in relation to the type of fertilizer applied. Chicken dung is high in nutrient content as evidenced from previous studies. Oil palm EFB was second best but cow dung was not suitable due to its poor nutrient content.

References

- Affendy H (2005) Growth performance of five indigenous species planted after nine years on degraded land in Pasoh Forest Reserve, Negeri Sembilan. B.Sc Thesis, University Putra Malaysia.
- Affendy H (2009) Intercropping of *Orthosiphon stamineus* (Benth) with *Hevea brasiliensis* (Willd) and *Durio zibethinus* (Murr) amended with various organic fertilizers and their financial analysis. M.Sc Thesis. Universiti Malaysia Sabah.
- Azani MA (1998) Rehabilitation of tropical rainforest based on natural canopy species for degraded area in Sarawak. Ph.D Thesis, Yokohama National University.
- Carter MR (1993). 'Soil Sampling and Methods of Analysis'. (Lewis Publisher: Canada)
- David D (2001). 'Determination of Total Kjeldahl Nitrogen in Soils and Plants by Flow Injection Analysis'. (Lachat Instruments Inc.: Milwaukee)
- Liu L Bates TE (1990) Evaluation of soil extractants for the prediction of plant-available potassium in Ontario soils. *Canadian Journal Soil Science* **70**, 607-615.
- Mehlich A (1984) Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. *Communications in Soil Science Plant Analysis*. **15**, 1409-1416.

- Nardi AD, D'Antonio CM, Dawson TE (2006) Depth of water acquisition by invading shrubs and resident herbs in a Sierra Nevada meadow. *Journal of Plant and Soil* **285**, 31-43.
- Olowolafe EA (2008) Effects of using municipal waste as fertilizer on soil properties in Jos area, Nigeria. *Resources, Conservation and Recycling* **52**, 1266 – 1270.
- Raja Barizan RS, Aminuddin M (1992) Nutrient requirements and deficiency symptoms in rattan plants. In 'A guide to the Cultivation of Rattan'. (Eds WM Wan Razali, J Dransfield, N Manokaran) (Kepong: Forest Research Institute Malaysia).
- Shao YT (1979) Effects of large scale land clearing for agriculture on soil fertility in the tropics. In 'Proceedings of Malaysian Seminar on Fertility and Management of Deforested land'. (Kota Kinabalu: Sabah).
- Soo YC (1990) Soil properties under *Acacia mangium* (Willd) stands of different ages. B.Sc. Thesis, Universiti Pertanian Serdang.
- Tan KH (2005) 'Soil Sampling, Preparation and Analysis(2nd edition)'. (New York: CRC Press).
- Yusop AR (2003) Relationship between foliar nutrient and soil properties of *Shorea acuminata* (Meranti rambai daun) under enrichment planting. B.Sc. Thesis, Universiti Putra Malaysia.
- Zahari I (2005) Vegetation association and sites preferences of Tongkat Ali (*Eurycoma longifolia* Jack) in a heath lowland forest, Pahang, Malaysia. M.Sc. Thesis, Universiti Putra Malaysia.

Soils-based evaluation of labile organic carbon and the role this may play in net soil mineralisation rates in Kiwifruit Orchard - Kaharoa ash soils of the Bay of Plenty, New Zealand

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Abstract

Nitrogen mineralisation processes are driven by factors that influence the microbial activity in soil which include soil temperature, moisture and soil carbon.

In order to describe the seasonal fluctuations of labile organic carbon samples from two conventionally managed blocks located at the Te Puke Research Orchard were collected monthly over 12 months. The soils of the two blocks are comparable with irrigated Hort16A vines growing in one block and un-irrigated Hayward vines in the other. These monthly samples were evaluated for mineral N and soil microbial activity, as measured using dehydrogenase assay, as well as for labile carbon. Soil evaluations for sites with contrasting management strategies (conventional verses organic) but soils of the same series and similar textures have also been compared.

Mineral-N levels are slightly higher at the 150-300 mm and the 300-450mm depths within the unirrigated Hayward block when compared to the irrigated Hort16A block. These differences may be due to the differences in vine activity at this stage of the season with the Hort16A block being further advanced with regard to canopy development and thus better able to take up the mineral-N available. There is no significant difference in labile carbon recorded between the two blocks. Microbial activity is reduced with profile depth and at this stage appears to demonstrate a reduction with time also. This drop in microbial activity may be linked to the overall drop in soil moisture content as the season progresses especially within the top 0-150mm. A strong statistical relationship was found between soil dehydrogenase activity and soil labile C concentrations within any one date over the 3 sampling depths. Within Kaharoa ash soils the organically managed orchard blocks demonstrate higher labile carbon and higher overall microbial activity than the conventionally managed systems.

Key Words

Nitrogen mineralisation, Hot water carbon, Microbial activity.

Introduction

Nitrogen (N)-mineralisation is driven by factors that influence the microbial activity in soil, including soil temperature, moisture (Cabrera and Kissel 1988; Sierra 1997), and the easily decomposable fraction of soil carbon, being the micro-organisms' energy source. This fraction is often termed "labile carbon". Hot-water-extractable carbon (HWC) is well suited to characterize the labile carbon fraction in pastures (Ghani *et al.* 2003) and orchards (Kim *et al.* 2008). Strong positive correlations between HWC and N-mineralisation rates in New Zealand soils have been observed. In apple orchards, HWC alone described about 50% of the variation in soil N mineralization rates in contrasting soils (Kim *et al.* 2008; Figure 1), or 80% when complemented by soil temperature and moisture.

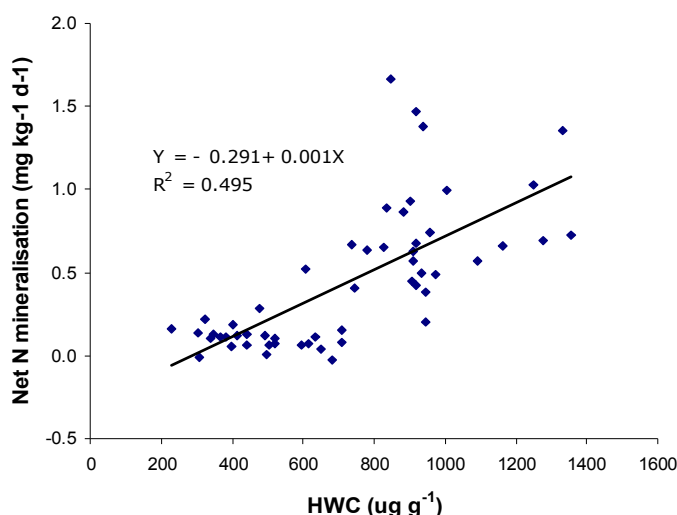


Figure 1. Net-N mineralization rate, evaluated following incubation for 40 days, as a function of the labile soil carbon (= hot water extractable carbon, HWC), (Kim *et al.* 2008).

A soil's labile carbon fraction is the result of both total carbon amount, and specific orchard management practices (Deurer *et al.* 2008). However, nothing is known of the impact that different management practices within kiwifruit orchards may have on this fraction and on actual or potential N-mineralization rates. We have focused on the Kaharoa ash soils of the Bay of Plenty, a predominant soil type for commercial kiwifruit.

Methods

Comparable soils from two conventional blocks at the Te Puke Research Orchard were sampled (0-15, 15-30, and 30-45 cm) monthly. Irrigated 'Hort16A' vines grow in one block (vine age 9 y) and un-irrigated 'Hayward' vines (vine age 36 y) in the other. Mineral N (Keeney and Nelson 1982), microbial activity (dehydrogenase assay (Chandler and Brooks 1991)), as well as labile C (hot water extraction (Ghani *et al.* (2003))) were determined over the course of a year (October 2008 to October 2009)

Soil samples were also taken from five conventional and five organic orchards in August 2008 to examine differences in labile C due to contrasting management strategies both within and between orchard rows, and to enable model parameterisation for calculation of N-mineralisation rates.

Results

Temporal changes in soil mineral N and labile C

Mineral-N levels (0-15 cm) varied little over the year except for peaks in December, February and September coinciding with the application of approximately 50 kg N/ha prior to sampling (Figure 2a).

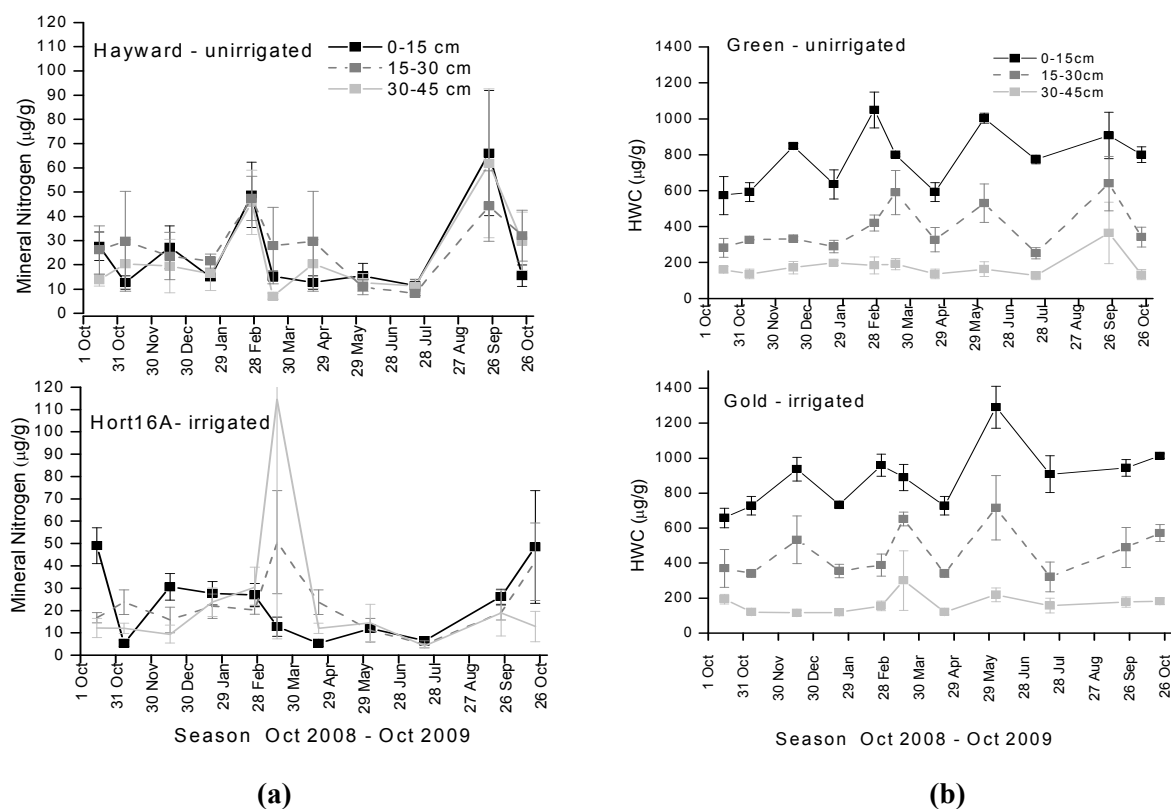


Figure 2. (a) & (b) Left. Mineral-N at three depths. Right. Hot water extractable C at three depths. Values are means of three samples $\pm$ one SE.

Mineral-N levels were slightly higher at the 15-30-cm and 30-45-cm depths in the unirrigated ‘Hayward’ block than in the irrigated ‘Hort16A’ block. These differences may be due to ‘Hort16A’ being further advanced in canopy development and thus better able to take up the available mineral-N.

Overall, there was no significant difference in labile C between the two blocks (Figure 2b). Labile C showed large temporal fluctuations, particularly in the 0-15 cm depth. There was a positive relationship between dehydrogenase activity and soil labile C within each sampling date (Figure 3). Labile C and dehydrogenase activity rates were both higher in the surface soils and declined with depth.

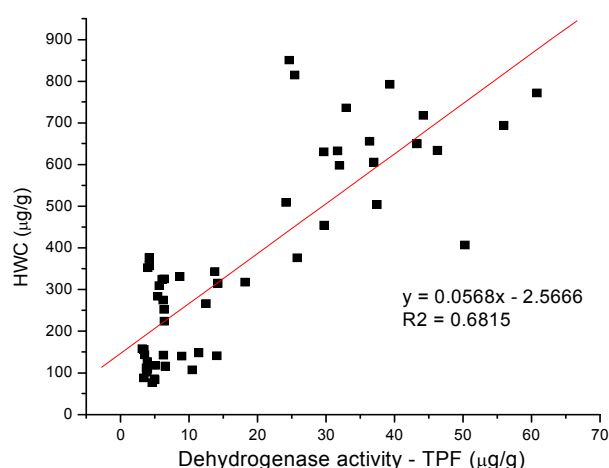


Figure 3. Labile soil carbon (= hot water extractable carbon, HWC) as a function of the microbial activity (Dehydrogenase activity).

2. Conventional versus organic orchard

Labile C was generally higher in organic than in conventional orchards (Figure 4), likely due to addition of compost and mulched plant material from vine clippings for N supply.

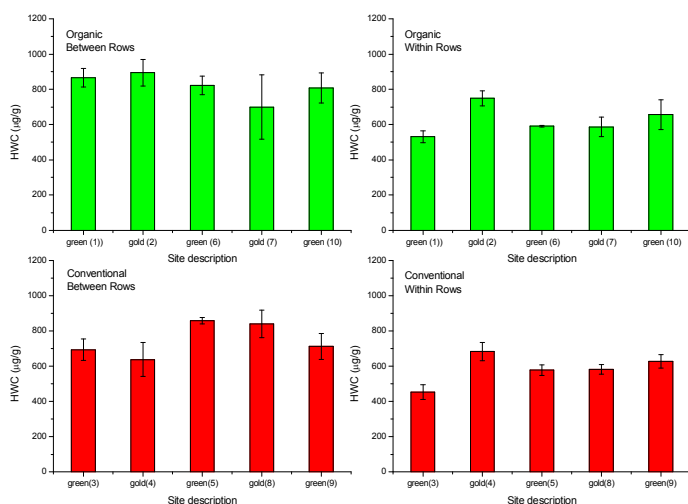


Figure 4. Soil labile C in organic and conventional orchards. Columns represent the mean ($\pm$ one SE) of four samples per property.

Conclusion

A good relationship with dehydrogenase activity within sampling dates suggests that hot water extractable C provides a useful measure of labile C in kiwifruit orchards.

Labile C can show large temporal fluctuations in irrigated and non-irrigated orchards; further work is needed to identify the cause(s) of this variation.

There was no clear evidence of a relationship between hot water extractable C and mineral N but further research is needed to examine the contributions of hot water extractable C to N mineralisation.

Organic orchards tended to be higher in labile C than conventional orchards, possibly due to inputs such as compost and mulched plant material from vine clippings.

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References

- Cabrera ML, Kissel DE (1988) Potentially mineralizable nitrogen in disturbed and undisturbed soil samples. *Soil Sci. Soc. Am. J.* **52**, 1010-1015.
- Chandler K, Brooks PC (1991) Is the dehydrogenase assay invalid as a method to estimate microbial activity in copper contaminated soils? *Soil Bio. Biochem.* **23**(10), 909-915.
- Deurer M, Sivakumaran S, Ralle S, Vogeler I, McIvor I, Clothier BE, Green S, Bachmann J (2008) A new method to quantify the impact of soil carbon management on biophysical soil properties: The example of two apple orchard systems in New Zealand. *J. Env. Qual.* **37**(3), 915-924.
- Ghani A, Dexter M, Perrott KW (2003) Hot-water extractable carbon in soils: a sensitive measurement of for determining impacts of fertilisation, grazing and cultivation. *Soil Biology and Biochem* **35**, 1231-1243.
- Keeney DR, Nelson DW (1982) Nitrogen – Inorganic Forms. In 'Methods of soil analysis, part 2. chemical and microbial properties, 2nd edition'. (Eds AL Page, RH Miller, DR Keeney) pp. 643-709. (American Society of Agronomy, Inc. and Soil Science Society of America, Inc. Pubs., USA).
- Kim I, Deurer M, Sivakumaran S, Huh KY, Green S, Clothier B (2008) N-Mineralisation in two apple orchards in Hawke's Bay: The impact of soil carbon management and environmental conditions. In 'Carbon and nutrient management in agriculture, proceedings of the 21st annual workshop of the Fertiliser and Lime Research Centre, Massey University) 13-14 February 2008, pp. 67-75.
- Sierra J (1997) Temperature and soil moisture dependence of N mineralization in intact soil cores. *Soil Biol. Biochem.* **29**, 1557-1563.

Sorption and bioavailability of phosphorus in soils as affected by coal combustion products

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Abstract

The retention and transformation of phosphorus (P) in soils, to which coal combustion products (CCPs) had been applied, were evaluated using sorption and fractionation experiments. Fly ash (FA), fluidised bed boiler ash (FB) and flue gas desulphurisation gypsum (FG) were applied (0%, 15% and 30%) to three different soils – loam (from Adelaide hills), silty loam (from Kapunda) and loamy sand (from Virginia agricultural land) and incubated for 21 days at 25°C. The soils were pre-treated with P from three different sources (potassium dihydrogen phosphate, poultry manure and rock phosphate) at the rate of 100 mg P/kg soil and 200 mg P/kg soil. In all soils, pH and P sorption increased with increasing application rates of FA and FB application. In the case of FG, both pH and P sorption decreased at the highest level of application. The fractionation of P in CCPs amended soils showed high concentration of P in Ca-associated P ($\text{H}_2\text{SO}_4\text{-P}$) followed by bioavailable P ($\text{NaHCO}_3\text{-P}$). Soil solution P ($\text{H}_2\text{O-P}$) decreased with increasing application rates of CCPs except for FG amended soils. The NaOH-P was relatively less responsive to CCPs application.

Key Words

P retention capacity, coal-fired power stations, eutrophication, run off, leaching, environmental degradation

Introduction

Phosphorus (P) has been the most limiting nutrient in most agricultural soils throughout the world. Australian soils are inherently deficient in P and are also poor in retaining P. Loss of P from soils through run off and leaching poses environmental degradation not only to the land resources but also to surface water (eutrophication) and ground water. Generally, P is transported from soil in particulate form and dissolved form (soluble inorganic P). Although the particulate P loss can be decreased through management practices such as riparian buffers, the soluble inorganic P loss had been an issue in soils having low P retention capacity (Mc Dowell *et al.* 2004). An understanding of P retention capacity (PRC) of soils is vital for fertiliser management and safeguarding water quality. High pH and high calcium (Ca) concentration in soil solution are good prerequisites for enhancing the retention of P in soils. Traditionally, lime (CaCO_3) has been widely used to overcome soil acidity, thereby enhancing P retention.

It has been shown that coal combustion products (CCPs) such as fly ash (FA), bottom ash and other by-products of the coal-fired power stations such as fluidised bed boiler ash (FB) and flue gas desulphurisation gypsum (FG) have been effective in decreasing soil solution P loss (Callahan *et al.* 2002; McDowell 2005; Stout *et al.* 2000). Some studies also showed the effectiveness of FA in mitigating particulate or organic P loss (Eg: Stuczynski *et al.* 1998a, 1998b), but the effectiveness was found to be pH and charge dependent (Reichert and Norton 1994). These coal ash materials can be an effective replacement for their natural counterparts if used judiciously. Hence, efforts have been taken globally on the possible usage of CCPs for increasing P retention in soils that are naturally poor in P retention.

Development of strategies to minimise the loss of P from soils requires a detailed understanding of P interactions and forms. Hence, the objective of this study was to examine the effect of CCPs on the retention and transformation of P in soils treated with various P sources.

Methods

Soils and coal combustion products:

The soils for the fractionation experiment were collected from three different locations around Adelaide, Australia – Adelaide hills loam (natural soil), Kapunda silty loam (natural soil) and Virginia loamy sand (Agricultural soil). All the soils were collected from surface (0-5cm), air-dried and sieved <2 mm depth. The

CCPs used for the experiment were fly ash (FA) from Port Augusta Power station, South Australia; fluidised bed boiler ash (FB) from Redbank Power limited, Queensland, and flue gas desulphurisation gypsum (FG) from Illinois, the United States. The P sources used for the experiment were potassium dihydrogen phosphate (PP), poultry manure (PM) and phosphate rock (PR). The basic characteristics of the materials used are given in Table 1.

Table 1. Basic characteristics of soils and CCPs used.

Materials	Sources	pH	EC ($\mu\text{S}/\text{cm}$)	Olsen P (mg/kg)	CaCO_3 equivalence
Soils	Adelaide hills – Loamy	5.6	30.04	3.82	-
	Kapunda – Silty loam	7.1	49.5	9.60	-
	Virginia – Loamy sand	7.3	364	88.31	-
CCPs	FB – Redbank Power, QLD	12.7	9.70	11.52	23.25%
	FG – United States	10.1	2.332	2.25	11.25%
	FA – Port Augusta	10.2	1.34	260.44	16.75%

Incubation

The soils (500 g each) were initially treated with the three P sources at the rates of 100 mg/kg soil and 200 mg/kg soil. The soils were incubated in a plastic bag for 21 days at 80% of the total water holding capacity (WHC). Soils incubated without P treatment served as control. After 21 days of incubation, all the P treated soils were incubated with 0%, 15% and 30% (w/w) of CCPs. The CCPs treated samples were again incubated for 21 days at 80% of the total WHC.

Fractionation experiment

The incubated soil samples were air-dried immediately after the incubation period and analysed for P fractions using Mc Dowell's fractionation methodology (Mc Dowell 2005), pH and EC. For this fractionation procedure, incubated soil samples (1 g each) were extracted sequentially by shaking with the following solutions: i. 30 mL of deionised water for 2 hours, ii. 0.5 M NaHCO_3 for 16 hours, iii. 0.1 M NaOH-I for 16 hours, iv. 0.5 M H_2SO_4 for 16 hours and v. 0.1 NaOH-II – Sonicated for 5 minutes and shaken for 16 hours. The remaining P was extracted by digesting the samples with *aqua regia* (concentrated $\text{HNO}_3:\text{HCl} - 3:1$). The P from the extracted samples were analysed using the colorimetric method of Murphy and Riley (1962).

Sorption experiment

For P sorption measurement, 1g of CCPs incubated soil was weighed into 50 ml centrifuge tubes and then mixed with 20 mL of P solution containing graded concentrations of P (0, 5, 10, 20, 50, 150, 500 mg P/L) as KH_2PO_4 (McDowell and Condron 2004). Then the tubes were shaken for 16 hours using a shaker at the room temp ($25^\circ\text{C} \pm 2$). The tubes were centrifuged for 20 minutes (4000 rpm) and filtered. The phosphate concentration of the filtered solutions was measured using the phosphomolybdate method (Murphy and Riley 1962). The amount of P sorbed was calculated from the difference between added and equilibrium concentrations.

The Freundlich equation (1) was used to fit the adsorption data and to estimate the sorption parameters.

$$S = K_f C^n \quad (1)$$

Where, S= Amount Adsorbed (mg/kg); C= Equilibrium Concentration (mg/L); n and K_f are constants.

Results

Fractionation experiment

The application of CCPs showed significant changes in P concentration and distribution of different P fractions. The highly responsive fractions to CCPs application were $\text{NaHCO}_3\text{-P}$ and $\text{H}_2\text{SO}_4\text{-P}$, where P concentration increased with increasing application rates of all the amendments (Figure 1). This is attributed to the increase in soil pH due to the liming effect of these CCPs, except FG (McDowell 2004). The $\text{NaHCO}_3\text{-P}$ and $\text{H}_2\text{SO}_4\text{-P}$ fractions were the major portions of the extracted P. Soil solution P (water-extractable P) in FA applied soils increased with increasing application rates of FA but showed decreasing trends on application of FB and FG. NaOH-P-I and NaOH-P-II fractions were relatively low in P concentrations; however, these fractions showed similar trends as other fractions on CCPs application. In all the fractions, FA application showed the highest P concentrations followed by FB and FG.

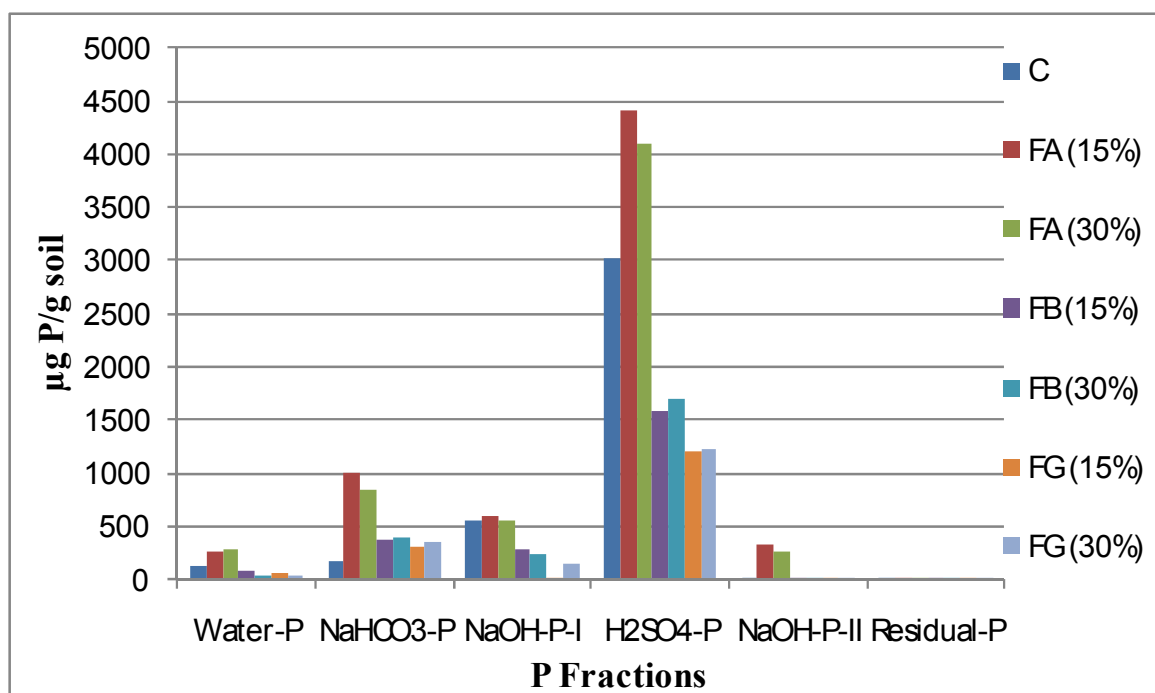


Figure 1. P fractions in CCPs amended soils.

Sorption experiment

Addition of CCPs increased the sorption of P as measured by the K_f value and except for FG the sorption of P increased with increasing levels of amendments (Figure 2 a and b). In the case of FG, the sorption of P decreased at the highest application rate.

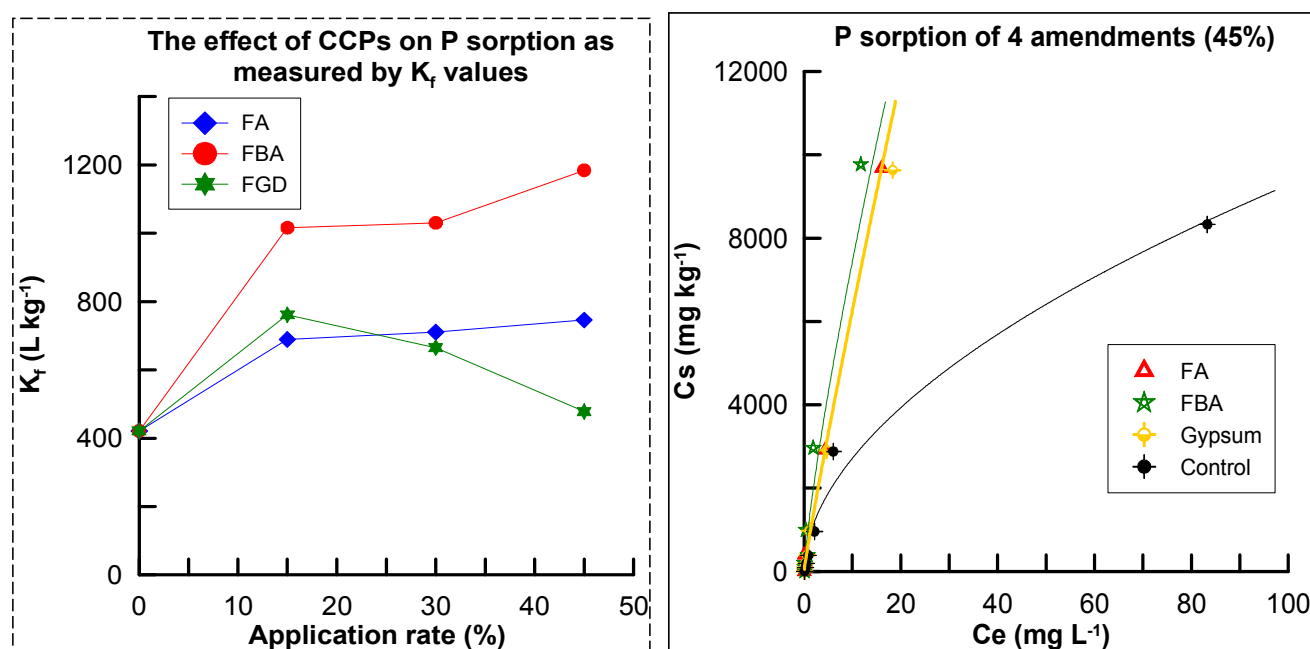


Figure 2a. The effect of CCPs on P sorption as measured by K_f value and b. P sorption of 4 amendments at maximum application rate.

The increase in P sorption with the addition of CCPs is attributed to an increase in soil pH (Figure. 3) and an increase in the concentration of aluminium (Al), Iron (Fe) and Ca in soil solution resulting in the formation of insoluble Al-P, Fe-P and Ca-P (McDowell 2004). The decrease in P sorption with increasing levels of FGD gypsum is attributed to the decrease in soil pH.

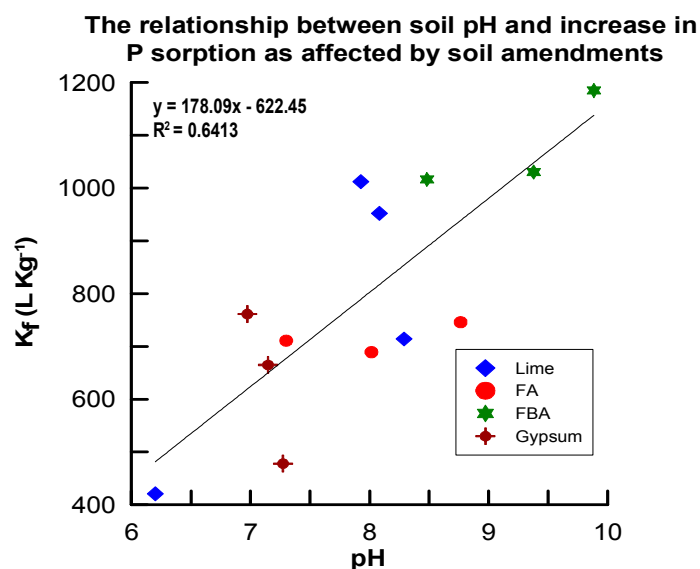


Figure 3. The relationship between soil pH and increase in P sorption as affected by soil amendments.

Conclusion

The results indicate that CCPs proved to increase the sorption and bioavailability of P in soils when applied at optimal rates. The sorption results indicate that CCPs are effective in enhancing the P retention capacity of soils by decreasing the soil solution P. However, some of these CCPs may contain heavy metals that are toxic to plants and animals. The toxicity of these heavy metals needs to be addressed using appropriate chemical and biological agents.

References

- Callahan MP, Kleinman PJA, Sharpley AN, Stout WL (2002) Assessing the efficacy of alternative phosphorus sorbing soil amendments. *Soil Science* **167**, 539-547.
- McDowell RW (2004) The effectiveness of industrial by-products to stop phosphorus loss from a Pallic soil. *Australian Journal of Soil Research* **42**, 755-761.
- McDowell RW and Condron LM (2004) Estimating phosphorus loss from New Zealand pastoral soils. *New Zealand Journal of Agricultural Research* **47**, 137-145.
- McDowell RW (2005) The effectiveness of coal-fly ash to decrease phosphorus loss from grassland soils. *Australian Journal of Soil Research* **43**, 853-860.
- Murphy J and Riley JP (1962) A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* **27**, 31-36.
- Reichert JM and Norton LD (1994) Fluidised bed bottom-ash effects on infiltration and erosion of swelling soils. *Soil Science Society of America Journal* **58**, 1483-1488.
- Stout WL, Sharpley AN, Landa J (2000) Effectiveness of coal combustion by-products in controlling phosphorus export from soils. *Journal of Environmental Quality* **20**, 1239-1244.
- Stuczynski TI, McCarthy GW, Wright RJ (1998a) Impact of coal combustion amendments on soil quality: I. Mobilization of soil organic nitrogen. *Soil Science* **163**, 952-959.
- Stuczynski TI, McCarthy GW, Wright RJ, Reeves JB (1998b) Impact of coal combustion amendments on soil quality: II. Mobilization of soil organic carbon. *Soil Science* **163**, 960-969.

Study of the degree of phosphorus saturation in Walloon Region (Southern Belgium)

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Abstract

Phosphorus losses from agricultural land can be a major source of eutrophication of surface waters. To meet the objectives of the Water Framework Directive, measures should be taken in agricultural soils. The degree of phosphorus saturation (DPS) is used in some countries to evaluate levels soil P saturation and subsequent risks of losses. The adequacy of this parameter to the Walloon situations had to be assessed before large-scale surveys. As a prior stage, this study has shown that $DPS = P_{ox} / 0.66 * (Al_{ox} + Fe_{ox})$ was relevant to study the P saturation of studied soils. A mean DPS of 32% was observed. Risks of P losses seem high in some areas and should be attributed to 2 factors: soil properties which drive the sorption capacity on the one hand and soil fertility management by farmers. A close relationship was found between DPS and available P and with sorption capacity and $P_{av}:P_{ox}$ ratio, which suggests that phosphorus availability is favoured when sorption sites are saturated, that is on soils with low PSC. However, as P transfers from soil to water may occur through particulate erosion, the total sorbed P should be taken into account too. DPS is thus of interest as environmental indicator but it shouldn't be used alone.

Key Words

Oxalate phosphorus, phosphorus sorption capacity, eutrophication, soil, indicator, fertilization.

Introduction

Just like as nitrogen, phosphorus (P) losses from agricultural soils can lead to eutrophication of surface water. P is essential for plant growth and may be considered as the main limiting resource for algae development in surface water. The surface water contaminations by human activities are a major concern in Europe and appropriate P management becomes crucial to meet the Water Framework Directive objectives. Measures have already been taken for some years to reduce urban P losses and agricultural diffuse inputs have become the major source of P in surface water. High rates of P fertilization result in P accumulation in soils which may lead to saturation of sorption sites and therefore increase risks of P loss to surface or groundwater via runoff or leaching. To evaluate these risks, we need environmental easily determinable and interpretable indicators and thresholds.

The Degree of Phosphorus Saturation (DPS) has already been used as an environmental indicator in some regions/countries all around the world, because DPS was shown to present a strong relationship with P runoff or P leaching. This parameter evaluates the proportion of soil exchange sites that are effectively bound to P.

$$DPS (\%) = 100 * P_{ox} / PSC \quad (\text{Van der Zee and Van Riemsdijk 1988}) \quad (1)$$

Where P_{ox} is oxalate-extractable P (mmol /kg) and PSC is the Phosphorus Sorption Capacity (mmol /kg). The soil PSC is a finite characteristic that depends on clay, organic matter, aluminium, iron, and calcium contents and pH. Factors that affect these properties such as soil type or land use also determine PSC. It can be estimated by (Börling *et al.* 2001):

$$PSC = \alpha (Al_{ox} + Fe_{ox}) \quad (2)$$

where Al_{ox} and Fe_{ox} are oxalate-extractable Al and Fe, and α is a scaling factor.

The oxalate solution is supposed to dissolve the poorly structured or amorphous oxides of Al and Fe which are the most active P binding sites (Paulter and Sims 2000).

The scaling factor α depends on soil type and experimental conditions. The α value of 0.50 has been largely used but its relevance was seldom verified. Some authors found different values that ranged from 0.44 (Van der Zee *et al.* 1988) to 0.68 (Paulter and Sims 2000) in other situations. Wrong estimates of α can therefore lead to serious misinterpretations of the soil sorption saturation.

This study aims to verify the dependency of DPS to soil type and agricultural soil fertility management in three important crop production regions of Southern Belgium. In the first step, the α scale factor was assessed for a selected set of soil samples representative of soil diversity in cultivated areas. Then, the relationships between DPS and soil characteristics as well as the influence of cultivation systems on DPS were investigated for selected farms.

Material and methods

Study Area and Soil Sampling

Six reference farms were selected within a network dedicated to the management of agricultural N-resources in Southern Belgium. These farms cover a wide range of soils, reliefs, and agricultural systems. They are located in three important crop production areas which are also the most problematic regarding phosphorus leaching, runoff and eutrophication. Soil samples were taken in 24 arable parcels. One composite (16 cores in a 2 m² area) topsoil sample (0 to 20 cm) was collected for each soil type within each parcel. Thus, one to five soil samples were collected within each of 24 fields for a total amount of 57 samples.

Chemical Characterization

All samples were dried at 40°C and sieved at 2 mm prior to storage and laboratory analyses. Soil pH in water (2:5) and 1N KCl (2:5) were measured and total organic carbon (TOC), total nitrogen (tN), cation exchange capacity (CEC), and clay content were predicted by near-infrared spectroscopy (NIRS). Available phosphorus (P_{av}) was determined following Lakanen-Erviö method (Lakanen and Erviö 1971). Oxalate extractable Fe (Fe_{ox}), Al (Al_{ox}) and P (P_{ox}) were determined after extraction with oxalate solution using a 1:20 (w:v) soil:solution ratio (Ross and Wang 1993). The suspension was equilibrated for 2 hours in the dark with continuous shaking, centrifuged (10'), and filtered. Al and Fe concentrations were measured by atomic absorption spectroscopy (AAS - VARIAN 220) and P by blue-colorimetry (Murphy and Riley 1962). PSC and DPS were calculated according to equations (1) and (2) (Van der Zee and van Riemsdijk 1988). The scale factor, α , was determined beforehand.

α determination

The use of the equation (2) requires the prior assessment of the α scale factor. This factor corresponds to the proportion of poorly crystallized Al- and Fe-oxides that can actually sorb P, known as total phosphorus sorption capacity (PSC_t). PSC_t is divided into P-occupied sites and remaining P sorption capacity (PSC_r) (Equation 3). The amount of P sorbed on the PSC_t is evaluated by oxalate-extractable P (P_{ox}) and PSC_r is calculated by multiplying an experimental P sorption capacity (F_r) by 2.75 (Equation 4). F_r is determined by the standardized one-point short-term isotherm method (Bache and Williams 1971). Three grams of 2 mm soil were shaken with 60 mL of a 75 mg P/L (as KH_2PO_4 equivalent to 1.5 g P/kg soil) 0.01 M $CaCl_2$ solution during 18 hours with some drops of chloroform. Samples were then centrifuged (10') and filtered (Whatman 602). Finally, the P remaining in solution was measured by colorimetry (Murphy and Riley 1962). The sorbed P (F_r) is calculated as the difference between added P and P remaining in solution. This method allows rapid appraisal of the remaining soil P-sorbing capacity. However short-term experiments usually under-evaluate PSC_r . To correct the estimates of PSC_r , the 18-hours F_r is multiplied by 2.75 (Maguire *et al.* 2001). Finally, the α scale factor can be estimated (equation 5).

$$PSC_t = PSC_r + P_{ox} \quad (3)$$

$$PSC_r = F_r * 2.75 \quad (4)$$

$$\alpha = \frac{P_{ox} + PSC_r}{Fe_{ox} + Al_{ox}} \quad (5)$$

The F_r , PSC_r , PSC_t parameters and α scale factor were determined for the 57 soil samples and the mean α was used to calculate PSC and DPS.

Results

Soil characteristics

Dominant soil order in the studied area is Luvisol, but some Fluvisols, Regosols and Leptosols were also observed. Textural classes, as assessed in the field, were mainly silt, sandy loam and clay loam. Soils were also differing by the quality of natural drainage observed by the depth and intensity of redox mottles. The soil characteristics measured in the laboratory are summarized in Table 1. The ranges for clay content

Table 1. Characterization of studied soils.

	Clay content (%)	Organic C (%)	Nitrogen (%)	CEC (cmol/kg)	pH _{water}	P _{ox} (mmol/kg)	Al _{ox} (mmol/kg)	Fe _{ox} (mmol/kg)	PSC (mmol/kg)	DPS (%)	P _{av} (mg/100g)
Frequency	53	57	56	57	27	57	57	57	57	57	57
Mean	15.8	1.4	0.13	13.1	7.6	15.4	29.8	46.4	50.3	32.0	12.8
Standard deviation	3.6	0.2	0.02	2.1	0.4	3.3	7.1	10.6	10.5	9.9	8.6
Coefficient of variation (%)	23.0	17.6	16.19	16.1	4.7	21.5	23.9	22.9	20.9	30.9	66.8
Minimum	6.7	0.9	0.08	7.6	6.5	6.2	18.4	27.2	32.7	12.9	2.4
Maximum	23.3	2.2	0.18	19.2	8.0	25.5	43.8	75.8	77.0	63.8	47.9

(6.7 to 23.3%) and CEC (7.6 to 19.2 cmol /kg) and the moderate CV reflect the influence of aeolian silt deposits which lead to relative homogenization of soil parent material in the studied area.

Compared to regional values for cultivated soils, the mean P_{av} of studied soils (12.8 mg P/100g) appears high. However, P_{av} presented the largest relative variability (CV = 66.8%) among measured or calculated soil characteristics probably due to the diversity of P management in studied farms.

α parameter assessment

Sorption isotherms were processed on studied samples to calibrate the α value to the regional natural environment. Our results for α values varied from 0.43 to 0.93, with a mean value of 0.66 and a standard deviation of 0.13. Clayey soils showed a higher α (mean of 0.88) than the other soils. This confirms that this parameter should be determined for each natural region according to soil map. The mean value of α is close to results of Paulter and Sims (2000) or Maguire *et al.* (2001), 0.68 and 0.65, respectively. Further DPS calculations (equation 2) in this study were based on the mean α value of 0.66.

Soil sorption saturation

PSC and saturation are summarized in Table 1, with the oxalate-extractable Al, Fe and P. All of them are moderately variable. A close relationship was observed between the P total capacity of sorption and the sum of Al_{ox} and Fe_{ox} which confirms that PSC_t of Belgian soils is controlled by amorphous Al and Fe. The remaining phosphorus sorption capacity (F_r) and DPS are logically negatively correlated. The more the soil is saturated with P, the less P-binding sites remain available.

Influence of soil properties on sorption capacity

The PSC depends on soil texture, clay content or CEC. The total sorption capacity ranged from 64 to 144 mmol./kg. It was higher in clayey or silty soils than in sandy soils. On that particular point, these latter soils are therefore more vulnerable to soil losses. In our study, farm 2 implemented a cultivation system with minimal P inputs. However, DPS appears relatively high, due to very low soil capacity. On the other hand, soil from farm 3 presented relatively high P content but the high PSC reduces the risks of P loss.

Influence of P management on DPS

The surface soils in this study presented DPS values ranging from 12.9 to 63.8%, with a mean of 32% (Table 1). In this study, some differences between farms were observed (Figure 1). For instance, farms 1 and 6 presented higher DPS than other farms, which we attribute to intensive pig farming. A 5-years P balance has been calculated for each farm and compared to DPS. No clear relationship could be found. DPS is a ratio which depends both on P management and soil characteristics. It allows a better evaluation of the P availability and the P loss risk, but is not a relevant agronomic indicator of past fertilization. Another ratio can be used to identify farms with P management presenting a risk for the environment. The ratio P_{av} / P_{ox} evaluates the fraction of sorbed P which is more susceptible to desorb and migrate to plants or in the soil. Figure 2 illustrates the relationship between this ratio and soil sorption capacity. The higher the PSC, the smallest the proportion of available P to sorbed P for the plant growth but also for the environment. This suggests that the binding strength depends upon the number of sites and that availability of P is improved with soil saturation. Figure 2 also allows one to distinguish intensive pig farming from other cultural systems.

Some thresholds have been proposed to DPS as environmental indicators. In the Netherlands, a threshold of 25% was proposed (Breeuwsma *et al.* 1995) and 40% in Flanders (Chardon and Schoumans 2007). According to that, 77% of our samples are above the Dutch threshold and 20% should be classified as saturated according to Flemish legislation. Care should then be taken when defining such thresholds. They should rely on effective measurements of P transfers from soil to surface waters.

The good relationship ($r=0.818^{***}$) between P_{av} and DPS shows the potential use of P_{av}, which is more easily measurable, for environmental indication. This relationship is even improved when the correlation analysis takes the texture into account.

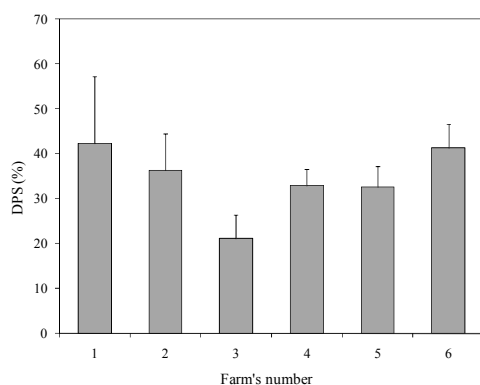


Figure 1. Mean DPS by studied farms.

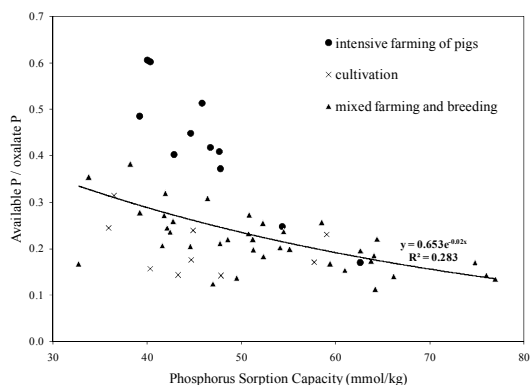


Figure 2. Relationship between available P/oxalate P and PSC.

Conclusion

DPS is an environmental indicator to estimate the P release to surface waters which can induce eutrophication. To be useful in Southern Belgium, the calculation of this parameter had to be adapted and the relationship with soil properties and P management were investigated. The study of the sorption capacity showed that fixing the α to 0.50, such as is done in many studies, overestimates the saturation status. A value of 0.66 would be more adequate for the Walloon situation. DPS is a double indicator. It allows one to determine the availability of P in the soil because DPS is well correlated with P_{av} . Moreover, this parameter shows also the capacity of a soil to retain additional P. Indeed, the remaining P sorption diminishes when DPS increases. The evaluation of DPS has shown that differences between regions were due to P management. DPS was higher in pig breeding areas. However DPS is also influenced by soil properties, and mainly by texture. The low PSC in sandy soils results in a high DPS, even if P content is low. That leads to environmental problems in some regions. These high DPS areas correspond to eutrophication areas. In consequence, DPS is a good environmental indicator which takes soil characteristics and P management into account. But to be used efficiently, thresholds should be developed for the Walloon context. Moreover, it shouldn't be used alone because they can't integrate the processes of soil-water transfers by particulate P.

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References

- Bache BW, Williams EG (1971). A phosphate sorption index for soils. *Journal of Soil Science* **22**, 289-301.
- Börling K, Otabbong E, Barberis E (2001) Phosphorus sorption in relation to soil properties in some cultivated Swedish soils. *Nutrient Cycling in Agroecosystems* **59**, 39-46.
- Breeuwsma A, Reijerink JGA, Schoumans OF (1995) Impact of manure on accumulation and leaching of phosphate in areas of intensive livestock farming. p. 239-251. In 'Animal waste and the land water interface'. (Ed. Steele K) pp. 239-251. (Lewis Publishing: New York)
- Chardon WJ, Schoumans OF (2007). Soil texture effects on the transport of phosphorus from agricultural land in river deltas of Northern Belgium, The Netherlands and North-West Germany. *Soil Use and Management* **23** (Supplement 1), 16-24.
- Lakanen E, Erviö R (1971). A comparison of eight extractants for the determination of plant available micronutrients in soils. *Acta Agraria Fennica* **123**, 223-232.
- Maguire RO, Foy RH, Bailey JS, Sims JT (2001). Estimation of the phosphorus sorption capacity of acidic soils in Ireland. *European Journal of Soil Science* **52**, 479-487.
- Murphy J, Riley JR (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytical Chemistry* **27**, 31-36.
- Paulter MC, Sims JT (2000). Relationships between soil test phosphorus, soluble phosphorus, and phosphorus saturation in Delaware soils. *Soil Science Society of America Journal* **64**, 765-773.
- Ross GL, Wang C (1993). Extractable Al, Fe, Mn, and Si. In 'Soil sampling and methods of analysis'. (MR CARTER ed.) pp. 239-246. (Lewis Publishing)
- Van der Zee SEATM, Nederlof MM, Van Riemsdijk WH, de Haan FAM (1988) Spatial variability of phosphate adsorption parameters. *Journal of Environmental Quality* **17**, 682-688.
- Van der Zee SEATM, Van Riemsdijk WH (1988). Model for long-term phosphate reaction kinetics in soil. *Journal of Environmental Quality* **17**, 35-41.

Study of the effects of rock phosphate application with phosphate solubilizing bacteria on P availability for corn

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Abstract

Rock phosphate is the source of chemical phosphorus fertilizers but its solubility is very low and one of the solutions for increasing its efficiency is application of phosphate solubilizing microorganisms. A greenhouse experiment was performed with *Bacillus subtilis* and *Pseudomonas putida*, five levels of rock phosphate (0, 25, 50, 75 and 100 percent of the difference to an optimum level of 16 ppm), in three soils with different amounts of available P (Low, Medium and High) in four replications. Their effects on single plant dry matter of corn and plant P uptake was determined using standard analytical methods. Results showed that *pseudomonas*, with maximum fertilizer treatments and soil with medium P had highest dry matter. Treatments without bacteria had highest P uptake, one of the reasons could be excretion of deleterious materials by bacteria. Fertilizer levels were not significantly different from each other. Perhaps it is because of the small differences between selected levels. In addition, applied rock phosphate had low solubility in these soils (pH= 7.5-8), even under the effects of phosphate solubilizing bacteria.

Key Words

Rock phosphate, bacillus, pseudomonas, phosphate solubility.

Introduction

Currently, about 800 millions of the world population suffers from malnutrition because of limitation of suitable food (FNCA Biofertilizer Project Group 2006). Some limitations in land use for agriculture could be overcome with application of suitable irrigation methods and use of fertilizers on nutrient deficient land. Phosphorus is necessary for all forms of life because of its genetic role in RNA and energy transformation by ATP. It is a factor for shorter growth period especially in cereals. Phosphorus deficiency effects metabolic processes such as transforming sugar to starch, and causes the production of anthocyanin. Phosphate fertilizers soon after spreading in the land, transform to low soluble or insoluble forms. Only 15 to 20% of phosphate fertilizer is available and a small portion of it will be taken up by plants. Roots can deplete or concentrate mineral phosphorus in the rhizosphere, and so change phosphorus availability (Havlin *et al.* 2004). Plants excrete organic acids such as citric, oxalic and tartaric acid to increase phosphorus solubility and availability in rhizosphere (Marschner *et al.* 1990).

Rock phosphates are the raw materials for production of phosphate fertilizers. Increasing of rock phosphate solubility rhizosphere of some plant species has been observed in alkaline soils. Application of rock phosphates of Iranian mines is not common, because of its low availability given the fact that most soils are alkaline, high pH, under drought stress, high bicarbonate in irrigation water and low organic matter. Yet researches have shown that rock phosphate application as a phosphate fertilizer along with the activity of soil microorganisms can be effective (Kang *et al.* 2002). Most soil microorganisms such as bacteria, fungi and actinomycetes have the ability to change insoluble phosphates to soluble forms. *Bacillus* and *Pseudomonas* are important genera of phosphate solubilizing bacteria. Phosphate solubilizing microorganisms can attain some of their nutritional needs directly from minerals, so temporarily transform them to available forms (Taalab and Badr 2007). Soil fertility and phosphorus efficiency depend on biological, chemical and physical complex interactions and processes in soil. The purpose of this experiment was to investigate the effect of phosphate solubilizing bacteria at different rates of rock phosphate in soils with different levels of available phosphorus, on corn yield and phosphorus uptake.

Materials and methods

A greenhouse experiment with randomized complete block design in factorial form and three replications of each treatment was conducted. Factors included three levels of bacteria treatments (control, *Bacillus subtilis*, and *Pseudomonas putida*), three soils with different levels of available phosphorus (0-5, 5-10, 10-15 mg/kg)

and five rates of rock phosphate application based on P requirement of each soil to reach an optimum of 16 mg/kg (including 0, 25, 50, 75 and 100 percent of the differences). Five kg pots were prepared with each soil and have fertilizers of nitrogen and potassium applied based on soil test. The phosphorus fertilizers were also applied for each treatment. Five corn seeds (DC370) were planted in each pot and thinned to three after the second week. Inoculation was done over the seeds after planting with phosphate solubilizing bacteria at a population of 1×10^8 cell/g soil. Above ground plant material was harvested after 75 days and dry matter yield per single plant and amount of plant phosphorus (Murphy and Riley 1962) were determined. Phosphorus uptake was also calculated. Results were analyzed by Gen-Stat software.

Results and discussion

The results indicated that medium P soil had highest dry matter and phosphorus uptake for all treatments ($P < 0.01$). (Results not shown). The mean of the 3 soil P ranges of the single plant D.M. showed the difference between fertilizer level treatments and that there was an increasing trend, although only the difference between 75% and 100% with control was statistically significant (Table 1). This could be due to the small difference between treatments in the lower range and low solubility of the fertilizer source. *P. putida* treatment had highest D.M. of single plant and was significantly different from control and *B. subtilis* treatments. P uptake of control treatment was highest compared to both bacteria treatments (Table 2) which may be due to decrease in the number of bacteria after inoculation as the competition between bacteria and plants for nutrient uptake. Changes in the available phosphorus content of all these soils between the start and the end of the experiment were much higher than the fertilizer inputs. This could indicate a other soil characteristics influenceing P solubility of the residual phosphorus of the soil, which perhaps will be more effective if inoculation with higher pH resistance strains of bacteria is practised in these soils (FNCA Biofertilizer Project Group 2006).

Table 1. Mean comparison of the interaction between fertilizer rate and treatment of bacteria on dry matter of single plant (g).

Bacteria	control	Bacillus subtilis	Pseudomonas putida	Mean total
Fertilizer (%)				
0	15.98 ^c	17.21 ^c	18.91 ^{bc}	17.37 ^c
25	18.79 ^c	19.9 ^{bc}	20.47 ^{bc}	19.72 ^b
50	20.19 ^{bc}	18.74 ^c	19.34 ^{bc}	19.42 ^b
75	20.69 ^{bc}	21.65 ^b	22.45 ^{ab}	21.6 ^a
100	20.85 ^{bc}	20.31 ^{bc}	24.79 ^a	21.99 ^a
Mean total	19.3 ^b	19.56 ^b	21.19 ^a	

Table 2. Mean comparison of the interaction between fertilizer rate and treatment of bacteria on plant phosphorus uptake (mg/pot).

Bacteria	control	Bacillus subtilis	Pseudomonas putida	Mean total
Fertilizer (%)				
0	64.33 ^{ab}	62.26 ^{ab}	60.03 ^{ab}	62.2 ^a
25	66.53 ^a	68.5 ^a	53.73 ^b	62.92 ^a
50	68.7 ^a	47.56 ^b	59.9 ^{ab}	58.72 ^a
75	69.33 ^a	54.7 ^b	65.93 ^a	63.32 ^a
100	64.46 ^{ab}	64.2 ^{ab}	62.3 ^{ab}	63.65 ^a
Mean total	66.67 ^a	59.44 ^b	60.38 ^b	

Conclusion

In conclusion, the results of this experiment indicated that solubility of rock phosphate used was very low and could not impose a significant effect on P availability on the relatively high pH soils used in this study. At the same time, the enhanced microbial activities due to bacterial inoculation or plant root exudates have had a positive effect on changes in availability of phosphorus in soil. Although, the trend and relative effectiveness of microorganisms in the soil are very complicated and unpredictable. It is suggested that for further studies, variation in plant, bacteria population and species, and the soil type be considered.

References

- FNCA Biofertilizer Project Group (2006). Biofertilizer- manual. Japan Atomic Industrial Forum (JAIF).
Havlin JL, Tisdale SL, Nelson WL (2004) 'Soil fertility and fertilizers: An introduction to nutrient

management'. (Prentice Hall).

- Kang SC, Ha CG, Lee TG, Maheshwari DK (2002) Solubilization of insoluble inorganic phosphates by a soil fungus *Fomitopsis* sp. PS 102. *Curr. Sci.* **82**, 439-442.
- Marschner H, Romheld V, Zhang FS (1990) Mobilization of mineral nutrients in the rhizosphere by root exudates. P. 158-163. In 'Transactions of the 14th Intl. Congress of Soil Science. Vol. 2. Kyoto, Japan'.
- Murphy J, Riley JD (1962). A modified single solution method for determination of phosphate in natural waters. *Anal. Chim. Acta.* **27**, 31-36.
- Taalab AS, Badr MA (2007) Phosphorus availability from compacted rock phosphate with nitrogen to sorghum inoculated with phosphor- bacterium. *Journal of applied Sciences Research* **3**, 195- 201.

Sulphur status of soils of the Cerrado region of Brazil and the ability of important agricultural soils of Brazil to oxidize elemental S

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Abstract

Expansion and intensification of agriculture in Brazil is putting increasing pressure on land resources and is increasing the need for good fertilizer management. Use of DAP and MAP, which contain little S, is increasing and freight costs for single superphosphate (SSP), which contains more S than P, may limit its use in areas distant from fertilizer plants. Four soils collected from no tillage sites in the Cerrado area of Brazil responded to P in both the absence and presence of S. There was no response to S in the absence of P in any soil and responses to S were recorded in the presence of P in soybeans in three soils, and in all four soils in maize. In the second pot study statistically significant responses to S were recorded in 13 of 21 soils. Responses to gypsum were recorded in 10 soils; responses to the predominately elemental S containing sulphur enhanced di-ammonium phosphate (DAP-SEF) in 9 soils and to powdered elemental S in 10 soils. Responses to the addition of soil inoculum containing S oxidising organisms, with elemental S occurred on only 2 soils indicating the presence of S oxidizing organisms in most soils studied. Yields following addition of gypsum and DAP-SEF were equal in 10 soils and gypsum produced higher yields than DAP-SEF in 3 soils. This study indicates that the addition of elemental S to DAP is a feasible way of providing S to crops in Brazil. The high nutrient density in an NPS fertilizer such as DAP-SEF, relative to SSP, would be expected to confer freight and spreading cost advantages resulting in lower nutrient costs to farmers.

Key Words

Elemental S, sulphate, Brazil, fertilizer.

Introduction

Sulphur is one of the essential elements required for the normal growth of plants and concentrations of S in plants are lower than that of N and similar to P. Sulphur plays an important role as a constituent of three amino acids which, if not present in adequate quantities, will reduce crop yield and sometimes the quality of produce. For many years, little attention was paid to sulphur as a plant nutrient mainly because it has been applied to soil in incidental inputs in rainfall and volcanic emissions, and as a component of N, P and K fertilizers. The awareness of sulphur deficiency is increasing, as is the development of S deficiency in previously S sufficient areas in many parts of the world. Intensification of cropping systems using high yielding varieties, such as is occurring in Brazil, has accelerated S removal from the soil, which is resulting in more soils becoming S deficient. Increased use of high analysis S free fertilizers has aggravated the S deficiency problem in many cropping systems. Plants take up sulphur from the soil solution as sulphate and, like nitrate, sulphate is mobile in most soils and can be easily leached from the rooting zone. Data from trials conducted in Australia showed that the loss of S from the root zone from an application of elemental S was approximately half that compared to that from gypsum over a 52 week period. Non-sulphate S sources, such as elemental S, must be converted to sulphate before the plant can access it. This oxidation process is primarily carried out by autotrophic bacteria in the *Thiomonas* genus, which use reduced S sources as their energy source. The question arises as to whether these organisms, or other S oxidizers, are present in soils that have not been fertilized with elemental S. This is important if elemental S containing fertilizers are to be introduced into nutrient management packages. Elemental S is an almost ideal fertilizer as it contains 100% nutrients. Since microorganisms that carry out the oxidation process are moisture and temperature dependant, as is the crop demand for S the S supply and demand are in synchrony. The rate of oxidation is also dependent on the particle size of S. This means that there is great scope to manage the release rate of sulphate to the plant to maximize plant uptake and minimize losses by surface runoff and leaching. Research carried out by Blair *et al.* (1979) has shown that plants require S and P early in growth and that oxidation rates are enhanced by intimate mixing of P and elemental S (Lefroy *et al.* 1997), which makes S inclusion into P containing fertilizers an attractive proposition. A process was invented in 2001 to include elemental S into DAP and MAP and a patent for this was filed in 2003. This group of fertilizers, collectively known as Sulphur Enhanced Fertilizers (SEF), is being introduced into agriculture in several countries, including Brazil.

Methods

Two separate studies were undertaken. The first was to investigate the responsiveness of some soils from the Cerrado region of Brazil to P and S and the second on the oxidation of elemental S in important agricultural soils in Brazil. In the first study samples from the 0-0.2 m soil layer were collected in the municipalities of Maracaju and Chapadão do Sul in Mato Grosso do Sul state and from two sites in Rondonópolis, Mato Grosso state. The samples were transported to the University of Sao Paulo, Piracicaba, air dried, screened to 0.2 mm and analyzed for pH, O.M., P, S, K, Ca, Mg, Al, H+Al, B, Cu, Fe, Mn, Zn, sand, silt and clay. The results of these analyses showed very low concentration of P for samples A, C and D, medium concentration of P for sample B and low concentration of S for all samples (Table 14). Clay content followed the order A = B >> C > D.

Results of soil chemical analysis indicated that soil C required liming so CaCO_3 and MgCO_3 was added to this soil to provide 25 and 8 mmolc/dm³ of Ca and Mg. Lime was not added to soils A, B and D. The greenhouse test was set up with the four soils (A, B, C and D), with 3 kg of soil per pot, with and without addition of P and S, two crops (soybean and maize) and three replicates. Rates used were 200 and 100 mg/kg of soil of P and S, respectively. Phosphorus was applied as monocalcium phosphate monohydrate and sulphur as potassium sulfate. In the zero sulphur treatments, potassium was added as KCl. Nitrogen was not applied to soybeans (plants were inoculated with *Rhizobium japonicum*) and was applied to maize at 250 mg/kg of N as urea at planting with two additional applications of 100 mg/kg each. To overcome the effects of other nutrients the chloride salts of Cu, Zn, Mn, B, Mo and Fe were applied at rates of 5, 10, 10, 2.5, 1 and 10 mg/kg of soil, respectively. Five seeds of Pioneer 30F33 maize or Conquista soybean were planted per pot and plants were thinned to two per pot seven days after emergence. The pots were watered daily using deionized water to maintain 75% field capacity. The plants were harvested after 50 days, dried at 60°C and weighed. Dry-matter yields were statistically analysed using SAS procedures.

Table 14. Soil analysis of the four samples collected for the greenhouse study.

SS Soil ID	Location	pH(CaCl ₂)	O.M. (g/dm ³)	P (mg/dm ³)	S(mg/dm ³)
A	Maracaju,	4.6	46	6	4
B	Chapadão do Sul	4.7	45	21	4
C	Rondonópolis 1	3.9	25	4	5
D	Rondonópolis 2	5.2	29	2	4

In the second study twenty-one soils from the major agricultural areas of Brazil were selected for the study. Soil samples (0-20 cm) were collected, dried and sent to the University of Sao Paulo, Piracicaba for the study. The soil samples were prepared by drying and sieving to 2 mm. Nutrients to overcome any nutritional effects other than S were applied at the rates of 200, 200 and 200 mg/kg of N, P, and K, respectively, in the form of urea, monocalcium phosphate and potassium chloride. A solution containing micronutrients, but no sulphur, was also applied. An additional amount of 100 mg/kg of P was added in soils with a clay content higher than 30%. Lime was applied at 0.5 g/pot, to overcome Ca and Mg deficiency. The sources of sulphur used were gypsum, DAP-SEF which is a granulated DAP sulphur enhanced fertilizer (16.7-39.4-0-11.7S, 3.8% of sulphur as sulphate S), powder elemental S (S⁰) and powdered S⁰ + soil inoculum. The amount of sulphur applied was 15 mg/kg. A control with no sulphur applied was added. The soil inoculum used was 1g / pot of soil from site 11 mixed with elemental sulphur. Site 11 had shown a response to an elemental S containing MAP indicating that sulphur oxidising microorganisms were present. As DAP-SEF has N and P in addition to S, a solution containing N and P was applied, where applicable, to balance N and P between treatments. The soils were initially cropped with two harvests of millet using all nutrients but no sulphur to reduce bioavailable S. All nutrients, except S, were mixed throughout the soil and the sulphur was localized in a thin layer 2 cm below the soil surface. Brachiaria grass was planted (Nov 01, 2006) with eight plants per pot. During plant growth the soil was maintained at 70% field moisture capacity. After harvesting the plant tissues were dried at 40°C for fifteen days and weighted for dry matter yield.

Results

In the first study responses to P were recorded in all four soils in both the absence and presence of S. There was no response to S in the absence of P in any soil and responses to S were recorded in the presence of P in soybeans in soils A, B and C, and in all four soils in maize (Table 15). Dry-matter yield of soybean was 19.1, 2.3, 26.3 and 9.0 times higher with the application of P in the presence of S on soils A, B, C and D, respectively. For maize the increments were of 15.7, 2.0, 26.9 and 84.0 times, respectively.

Table 15. Dry-matter yield (g/pot) of soybean and maize as affected by P and S.

Soil ID	S applied (mg/kg)	Soybean DM yield (g/pot)		Maize DM yield (g/pot)	
		P applied (mg/kg)		P applied (mg/kg)	
		0	200	0	200
A	0	1.7	28.9	4.3	36.5
	100	1.9	36.4	4.6	72.3
		lsd = 4.1		9.0	
B	0	11.2	22.3	15.0	46.4
	100	12.2	27.9	35.6	69.9
		lsd = 5.5		6.6	
C	0	0.2	11.8	1.7	45.6
	100	0.7	18.4	2.6	70.0
		lsd = 6.1		8.6	
D	0	0.2	0.9	0.6	42.7
	100	0.3	2.7	0.7	58.8
		Ns		7.0	

Dry-matter yield of soybean was 1.3, 1.3, 1.6 and 3 times higher with the application of S in the presence of P in soils A, B, C and D, respectively. For maize the increments were of 2.0, 1.5, 1.5 and 1.4 times, respectively. As expected, response to S was lower than the response to P, but dry-matter yields with the application of S in the presence of P were statistically higher than without the application of S in the presence of P. Low dry-matter yield of soybean in soil C, and especially in soil D, was due to B toxicity in these sandy soils. In the second study statistically significant responses to S were recorded in 13 of the 21 soils (Table 3). Responses to gypsum were recorded on 10 soils, responses to the predominately elemental S containing DAP-SEF on 9 soils and to powdered elemental S on 10 soils. Addition of soil inoculum resulted in an increase in yield above the S⁰ treatment on only 2 soils (4 and 7). Yields following addition of gypsum and DAP-SEF were equal in 10 soils and gypsum produced higher yields than DAP-SEF in 3 soils.

Table 16. Sulphur responses in dry matter yield (g/pot) of Bracharia grown in 21 soils from throughout Brazil. Numbers in bold parentheses are significantly different from the control in that soil.

Soil #	Control	Gypsum	DAP-SEF	So	So + inoculation	S response	Inoculation response	DAP-SEF v Gypsum
(-----g/pot-----)								
1	20.5	24.2	22.8	23.4	28.2 ^A	yes	yes	equal
2	21.4	28.0	26.2	25.5	28.4	yes	no	equal
3	26.2	27.7	29.5	28.3	26.7	no	no	-
4	19.8	28.8	28.6	24.5	31.4	yes	yes	equal
5	28.3	25.8	29.2	26.0	29.0	no	no	-
6	21.8	24.3	25.7	26.2	25.0	no	no	-
7	26.5	29.7	27.9	27.1	32.1	yes	yes	equal
8	16.8	21.5	19.2	23.2	17.6	yes	no	Equal
9	13.0	11.3	14.2	12.4	11.7	no	no	-
10	20.9	26.6	28.6	31.5	30.1	yes	no	Equal
11	24.5	31.3	30.1	33.5	34.2	yes	no	Equal
12	21.3	34.5	29.0	32.4	35.1	yes	no	inferior
13	12.5	22.6	21.8	21.4	23.5	yes	no	Equal
14	18.8	24.6	24.1	26.1	28.2	yes	no	Equal
15	17.6	26.1	23.8	27.2	26.7	yes	no	Equal
16	11.3	16.6	14.6	17.9	18.3	yes	no	inferior
17	25.3	26.3	28.4	28.0	24.7	no	no	-
18	9.2	21.5	16.4	15.4	17.9	yes	no	inferior
19	7.0	4.3	5.7	3.6	4.8	no	no	-
20	7.6	9.7	9.5	11.2	9.3	no	no	-
21	18.9	19.8	18.6	22.6	21.8	no	no	-
S response	10	9	11	12	13	3		

^A Numbers in bold italics are significantly different from the control

Conclusion

The four soils from the Cerrado region of Brazil studied here were very responsive to P and three of the four were responsive to S in the presence of P. In a wider survey of 21 soils, 13 were found to be responsive to S and there was little difference in the yield produced from sulphate and elemental S. Introduction of S oxidising organisms had little effect on crop yield which indicates that elemental S containing fertilizers could be satisfactorily introduced into Brazilian agriculture.

Acknowledgements

These studies were undertaken when the senior author was a Professor at ESALQ, University of São Paulo, Piracicaba, Brazil. Since completion of the studies development of the experimental SEF fertilizer has been continued in Canada and the USA by Shell Canada Energy to the stage where it is now produced commercially in Australia using the Thiogro process, and consideration is being given to its production in other countries.

References

- Blair GJ, Momuat EO, Mamaril CP (1979) Sulphur nutrition of Rice. II. Effect of source and rate of S on growth and yield under flooded conditions. *Agronomy Journal* **71**, 477-480.
- Lefroy RDB, Sholeh, Blair G (1997) Influence of sulphur and phosphorus placement, and sulphur particle size, on elemental sulphur oxidation and the growth response of maize (*Zea mays*). *Australian Journal of Agricultural Research* **48**, 485-495

The effect of P fertiliser application strategy and soil P sorption properties on 'incidental' P fertiliser characteristics using laboratory techniques and long term Bayesian risk modelling

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Abstract

The occurrence of rainfall and runoff soon after phosphorus (P) fertiliser application (fertiliser 'incidental' effect) can increase P exports. In this paper we firstly use a laboratory study to examine the effect of soil properties on the duration of the incidental fertiliser effect. Secondly we examine the effect of P fertiliser strategy – single v split applications – on long-term runoff P risk using laboratory and catchment runoff data in a Bayesian risk model. We found that soil P buffering characteristics have a large effect on the duration of incidental fertiliser effect. Despite the disproportionately large effect of a single application on runoff P concentration compared to split applications, the increased likelihood of runoff and fertiliser application coinciding when fertiliser applications were split, mean that the overall risk of runoff P loss is increased with split fertiliser applications. Farmers should therefore apply P fertiliser in a single annual application and apply this when risk of runoff is low, the importance of this strategy being greatest for farmers on soils with moderate to low P buffering.

Key Words

Phosphorus, incidental, risk, Bayesian, runoff, fertiliser.

Introduction

The export of phosphorus (P) in surface runoff from intensively managed pasture is often greater than is desirable and can contribute to eutrophication of waterways. The concentration of P in runoff is a function of systematic and incidental factors. The systematic components include unavoidable factors (e.g. optimal soil P status and grazing activity) and avoidable factors (e.g. soil P in excess of plant requirements). The incidental components – also referred to as avoidable (Hart *et al.* 2004) - include the effect that fertiliser and dung application have when they are followed shortly by runoff.

The occurrence of runoff in the days following fertiliser application can result in increases in runoff P concentrations of 10-100 mg/L (Bush and Austin 2001; Hart *et al.* 2004; Nash *et al.* 2005). Although the 'incidental' fertiliser effect only lasts for a short period - typically less than 30 days (Hart *et al.* 2004) and its contribution to P loss relies on the coincidence of this effect and runoff, the high concentrations of P in runoff, should this occur, means that it has the potential to make a major contribution to P export.

As a result of increasing basal soil P status under dairy pastures, there is a trend of increasing use of split fertiliser applications, i.e. applying the annual P fertiliser application in several smaller amounts equal to the equivalent total. This may reduce the incidental runoff P concentrations should they occur, but the risk of coincidence of runoff and fertiliser application may also increase.

In this paper, we report results from laboratory investigations examining the effect of soil P properties on the duration of the incidental fertiliser effect and the effect of single vs split fertiliser applications using a combination of laboratory and Bayesian runoff risk modelling.

Methods

Soils under pasture were collected from six sites located at a range of locations in New South Wales and Tasmania to a depth of 0-2 cm. They were selected to provide a wide range of P buffering indices (PBI) (Burkitt *et al.* 2008) ranging from extremely low (Richmond) to extremely high (Avoca) (Table 1). The soil samples were then dried at 40°C under forced draft before being sieved to <2mm to remove plant and particulate debris.

The effect of soil P buffering on incidental fertiliser effects

We firstly examined the effect of soil P buffering on the changes in extractable P following fertiliser addition (40 kg P/ha) using the six soils described in Table 1. The soils were packed in to 40 mm internal diameter tubes to a bulk density of 1.0 g/cm³, with moisture adjusted to 0.3 bars and fertiliser granules added. CaCl₂-P was determined by shaking the soil in the tubes at a 1:5 soil:solution ratio with 0.01M CaCl₂, centrifuging (1300 g), filtering (<0.45 µm) and determining molybdate reactive P using colorimetry (Murphy and Riley 1962). Fertiliser half-lives were determined and the relationship with soil PBI examined. The use of CaCl₂-P as a surrogate for runoff P concentrations is based on a highly significant linear relationship between CaCl₂-P and runoff P we previously found on a range of Australian soils (unpublished).

Table 1. Selected soil properties

Soil	Australian classification (Isbell 1997)	pH (CaCl ₂)	Total P mg/kg	Colwell P	PBI
Avoca (NSW)	Ferrosol	4.9	670	12	730
Elliott (Tas)	Ferrosol	5.1	1200	51	550
Camden (NSW)	Brown Chromosol	5.2	640	52	95
Mt Hicks (Tas)	Brown Dermosol	4.7	750	76	200
Richmond (NSW)	Dermosol	5.4	210	31	26
Togari (Tas)	Hydrosol	5.1	760	150	110

Incidental fertiliser risk under two fertiliser application strategies

We then compared the cumulative risk of two fertiliser application strategies, namely a single application of fertiliser (40 kg P/ha) or split applications (3×13.3 kg P/ha) to achieve the same total P application on one of the six soils. In order to compare these risks, CaCl₂-P (as per previously described methods) was determined under the two fertiliser strategies and a control (0 kg P/ha). The two fertiliser strategies were triple superphosphate applied as either one application of 40 kg P/ha at T0, or three applications of 13.3 kg P/ha at 25 day intervals (T0, T25, T50). These treatments were applied to the Togari soil and soil moisture was controlled as described previously. The extractions were undertaken at day 0, 1, 3, 6, 12, 25, 26, 28, 31, 37, 50, 51, 53, 56, 62, 75 and 127, with four replicates per treatment.

In order to consider the potential impact of these two fertiliser strategies on P loss in a temporally variable runoff context, we used a Bayesian modelling approach that combined the area under the CaCl₂-P curve and long term runoff data. The long term modelled surface runoff data (1961-2008) was from two catchments in Tasmania. Two catchments were selected to represent contrasting rainfall/runoff patterns which commonly support dairying in Australia. Average annual rainfall for the Montagu catchment (far north west Tasmania) is 1125 mm and the rainfall pattern is highly winter dominant. In contrast, the Ansons Bay catchment (north east Tasmania) receives an average annual rainfall of 786 mm and although rainfall in this catchment is higher in winter, rainfall and surface runoff patterns are more erratic and less winter dominant than the Montagu catchment.

Results

The effect of soil properties on incidental fertiliser effects

For all soils, there was a rapid decrease in CaCl₂-P with time since fertiliser application. The exponential decay relationship between PBI and half life was highly significant ($P < 0.001$) and is shown in Figure 1. This study is the first to our knowledge that shows this affect of PBI on half life. The effect of PBI is particularly pronounced in the <150 PBI range, typical of a large number of dairy farms in Australia. These findings may explain the wide range of half lives reported by Hart *et al.* (2004). The data suggest that on soils with high P buffering capacities, incidental fertiliser effects are likely to be generally unimportant.

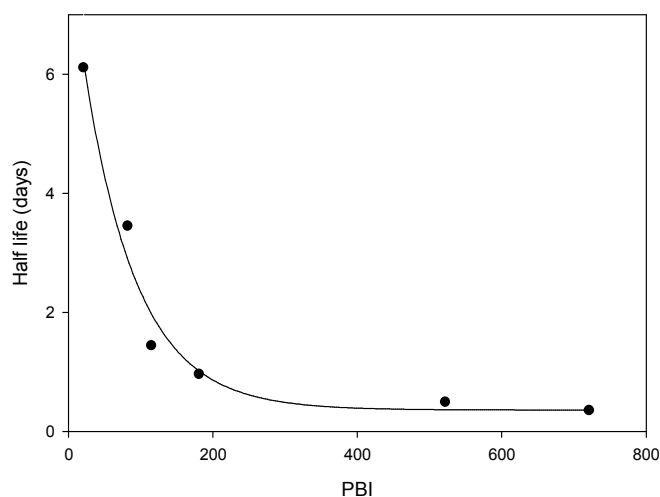


Figure 1. The relationship between soil phosphorus buffering index and fertiliser half lives.

Incidental fertiliser risk under two fertiliser application strategies

The CaCl_2 extractable P concentrations for the control, single and split P applications are shown in Figure 2. The addition of P fertiliser increased the extractable P concentration. The addition of 40 kg P/ha resulted in a disproportionately large increase in extractable P concentration compared to the first application of 13 kg P/ha immediately after P fertiliser application. The first application of 13 kg P/ha increased extractable P concentration from ~5 to 25 mg/kg (~5 fold increase), whereas the addition of 40 kg P/ha increased extractable P concentration from ~5 to 205 mg/kg (~41 fold increase). For each of the three split P additions, CaCl_2 -P measured immediately after each successive addition (T0, T25 and T50) significantly increased ($P < 0.05$; LSD = 7) with each subsequent addition (25, 56 and 75 mg/kg respectively). This increase in CaCl_2 -P with repeated applications is consistent with a declining P sorption capacity with each additional P addition (Barrow *et al.* 1998).

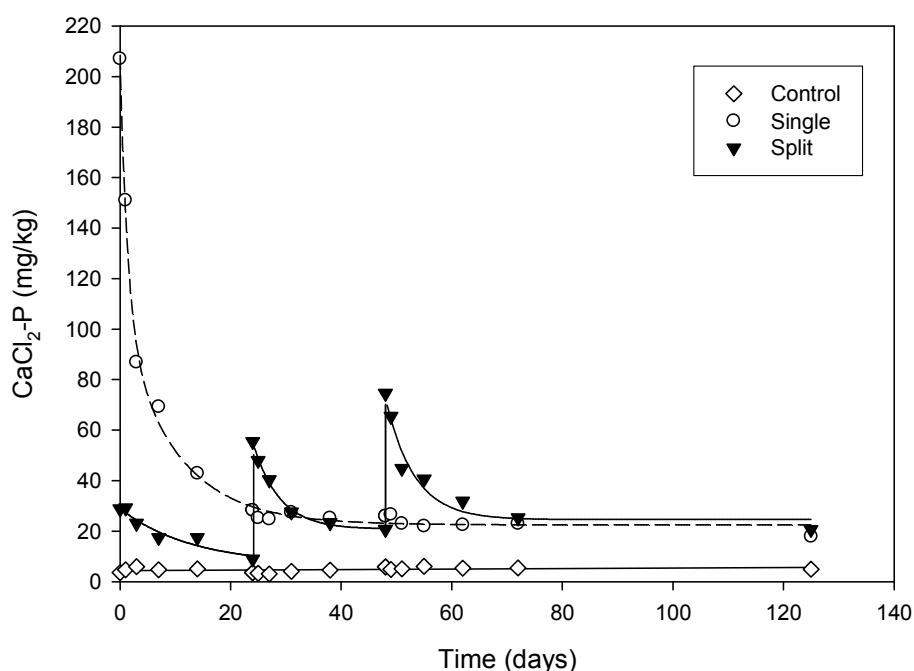


Figure 2. The change in CaCl_2 P with cumulative number of days for the control ($\diamond$), single application of 40 kg P/ha ($\circ$) and 3 split applications of 13.3 kg P/ha ($\blacktriangledown$). Values presented are a mean of six replicates. Phosphorus fertiliser was added at T0 (single and 1st split treatments) and T25 and T50 (2nd and 3rd split treatments).

Our Bayesian risk model revealed that 3 applications of 13.3 kg P/ha resulted in a greater risk compared to a single application of 40 kg P/ha and was significant in both catchments (posterior probability $P > 0.95$).

From a nutrient management perspective, single, annual applications of P fertiliser are likely to result in lower P runoff losses, especially if P fertiliser application can be applied when the chances of surface runoff are less likely (i.e. early autumn or late summer). This could represent a practical P management option considering that Burkitt *et al.* (unpublished) concluded that the timing or number of split applications of P fertiliser had no effect on pasture production when soil extractable P concentrations were already apparently adequate based on published agronomic soil test P values.

Conclusion

This study, has for the first time, demonstrated that the duration and hence importance of the fertiliser incidental effect is a function of soil P buffering properties. These findings will have important implications for the identification of soils at highest risk of P runoff and have demonstrated that particular attention needs to be paid to timing of fertiliser application on soils with low PBI. The strategy of splitting fertiliser applications increases the overall risk of runoff P loss and should be avoided in favour of single applications at low runoff risk times of the year.

References

- Barrow NJ, Bolland MDA, Allen DG (1998) Effect of previous additions of superphosphate on sorption of phosphate. *Australian Journal of Soil Research* **36**, 359-372.
- Burkitt LL, Sale PWG, Gourley CJP (2008) Soil phosphorus buffering measures should not be adjusted for current phosphorus fertility *Australian Journal of Soil Research* **46**, 676-685.
- Bush BJ, Austin NR (2001) Timing of Phosphorus Fertilizer Application within an Irrigation Cycle for Perennial Pasture. *Journal of Environmental Quality* **30**, 939-946.
- Hart MR, Quin BF, Nguyen ML (2004) Phosphorus runoff from agricultural land and direct fertilizer effects: A review. *Journal of Environmental Quality* **33**, 1954-1972.
- Isbell RF (1997) *The Australian Soil Classification*, CSIRO Publishing, Melbourne, Victoria.
- Murphy J, Riley JP (1962) A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* **27**, 31-36.
- Nash D, Clemow L, Hannah M, Barlow K, Gangaiya P (2005) Modelling phosphorus exports from rain-fed and irrigated pastures in southern Australia. *Australian Journal of Soil Research* **43**, 1-11.

The effect of soil available P and P buffering on runoff P concentration from pastures

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Abstract

Phosphorus (P) in surface runoff from agriculture can contribute to the eutrophication of surface waters. A poor ability to predict which soils are particularly susceptible to P loss based on routine soil testing limits our ability to prioritise soils for nutrient management. We postulated that the combination of soil quantity and buffering measures may provide a better method of predicting runoff P concentration. In this study we examined the effect of soil P (Colwell P) and phosphorus buffering on runoff P concentrations for six soils with widely varying phosphorus buffering characteristics. For each soil there were 15 runoff trays encompassing a wide range of soil Colwell P. For each soil, there was a highly significant ($P \leq 0.01$) curvilinear relationship between Colwell P and runoff P. However, these relationships varied widely between soils. A simple model using the parameters Colwell P and phosphorus buffering index explained 80% of the variation in runoff concentration for all soils. The results show that soils with moderate to low P buffering and available P above the agronomic optimum should be a priority for improved P management.

Key Words

Phosphorus, runoff, modelling, buffering, available P.

Introduction

Concentrations of phosphorus (P) in runoff from intensively managed pasture used for dairying are often high. Elevated concentrations of P in surface waters can contribute to increases in algal growth and consequently a decline in the environmental health and amenity of waterways. In studies on one soil, or a narrow range of soil types, soil P is an important determinant of runoff P concentrations in pasture systems (for example Dougherty *et al.* 2008; Robertson and Nash 2008). Yet soil P concentrations poorly predict runoff P concentrations across widely differing soils.

Accurate identification of areas of land of greatest runoff P risk using indices such as recently developed Australian Farm Nutrient Loss Index (FNLI) (Gourley *et al.* 2007) is based upon an understanding of the effect of source factors on runoff P concentrations – soil P being one of these source factors. The poor accuracy of predictions of runoff P concentrations means that areas of risk cannot be reliably identified and consequently the potential benefits arising from implementing particular best management practices (BMPs) and the adverse effects of applying more nutrients are also poorly defined

The objective of the research reported herein was to evaluate the potential of routine measures of soil test P or associated parameters (such as the phosphorus buffering index - PBI) to predict runoff P on a suite of soils with diverse soil P buffering properties.

Methods

Soil collection and runoff tray establishment

Soil (0-10 cm) was collected from 6 sites (5 in NSW and 1 in South Australia), these sites having a wide range of soil P buffering properties as measured by the phosphorus buffering index (PBI) (Burkitt *et al.* 2008). Soil was mixed thoroughly (<5 mm) and rocks and large plant roots removed. For each site, 15 runoff trays were constructed (Anon 2002) into which soil was repacked and sown to pastures. Prior to this repacking, P was added as triple superphosphate at varying rates and mixed thoroughly in a cement mixer to generate a wide range of soil P for each soil type. The amount of P required to be added was estimated using relationships derived from Burkitt *et al.* (2002). The trays were incubated and pastures grown for eight months prior to rainfall simulations.

Table 1. Selected soil properties

Soil ID	Location	Soil type (Isbell 1997)	Total P	Colwell P ^a mg/kg	PBI	OxAl mg/kg	OxFe mg/kg
Camden	NSW	Brown Chromosol	510	39	87	3261	1305
Flaxley	SA	Brown Chromosol	690	10	110	3834	2518
Glenmore	NSW	Red Chromosol	1100	67	180	5143	2891
Moss Vale	NSW	Brown Kurosol	370	10	540	4391	4263
Richmond	NSW	Red Kandosol	220	36	32	974	1089
Robertson	NSW	Red Ferrosol	1200	28	1600	11143	5956

Rainfall simulations

The trays were placed at a slope of 5% then subject to rainfall simulation at 45 mm/hr using a TeeJet 3/8 HH SS 24 WSQ (Spraying Systems Co., Wheaton, IL). Rainfall simulation was continued for 30 minutes after runoff commenced. A single composite runoff sample was collected and immediately filtered <0.45 µm. The filtered samples were analysed for dissolved reactive P using colorimetry (Murphy and Riley 1962). Total P (TP) and total dissolved P (TDP) were determined on un-filtered and filtered samples respectively following digestion using an acidic persulfate procedure and subsequent determination of P using colorimetry (Murphy and Riley 1962).

For each tray, twenty soil (0-1 cm) cores (2 cm diam.) were collected and composited. Soil samples were air-dried at 40°C then ground and passed through a 2 mm sieve to remove stones and plant debris. The samples were then stored at 4°C prior to analysis. Soil Colwell P (Colwell 1963) was determined by shaking soil for 16 h at a soil:solution ratio of 1:100 and subsequent filtration (<0.45 µm) and determination of P using colorimetry (Murphy and Riley 1962).

Results

The additions of P achieved a wide range of Colwell P concentrations. For each soil type there was a consequent large range in runoff P concentrations (30-50 fold), that tended to increase with increasing Colwell P. In general, for a given Colwell P value, the runoff P concentrations appeared to be greater for the lower PBI soils and to decrease as PBI increased. The majority of runoff P was in the form DRP (~75%).

The relationship between Colwell P and runoff DRP are shown in Figure 1. For each of the soils, there was a highly significant ($P < 0.01$) curvilinear (exponential) relationship between Colwell P and DRP. However, these relationships varied widely. The concentration of P in runoff was higher for the soils with lower PBI. For example, the Richmond soil (PBI ~ 30) had very high runoff P concentrations whereas the Robertson soil (PBI~1500) had very low runoff P concentrations. There was no relationship ($P > 0.05$) between Colwell P and DRP for all soils combined. These data clearly show that Colwell P is an extremely poor indicator of runoff P concentrations across a wide range of soil P buffering properties.

We postulated that a model that included soil quantity and buffering terms may provide a better prediction of runoff P concentrations. This was tested using the following model:

$$\ln P = \alpha + (\beta \times \ln \text{Colwell P}) + (\gamma \times \ln \text{PBI}) + (\delta \times \ln \text{Colwell P} \times \ln \text{PBI}) \quad (1)$$

where the dependent variable 'P' refers to the various forms of runoff P (i.e. DRP, TDP and TP). In the case of all runoff P fractions, the term $\ln \text{PBI}$ was eliminated after being found not-significant ($P > 0.05$). The curvilinear nature of the relationship is consistent with a decreasing P buffering capacity of the soils as P is added (Barrow *et al.* 1998). This decrease in buffering is confirmed by the exponential relationship between Colwell P and $\text{CaCl}_2\text{-P}$ – an approximation of a quantity-intensity relationship (not shown).

Table 1. Model parameters and estimates. Values in parentheses are standard errors of parameters.

Term	DRP	TDP	TP
Constant	-12.752 (0.679)	-12.215 (0.841)	-9.607 (0.630)
$\ln \text{Colwell P}$	2.503 (0.123)	2.396 (0.153)	1.016 (0.114)
$\ln \text{Colwell P} \times \ln \text{PBI}$	-0.130 (0.009)	-0.130 (0.011)	-0.100 (0.008)
r^2	0.84	0.76	0.79
Significance	$P < 0.001$	$P < 0.001$	$P < 0.001$

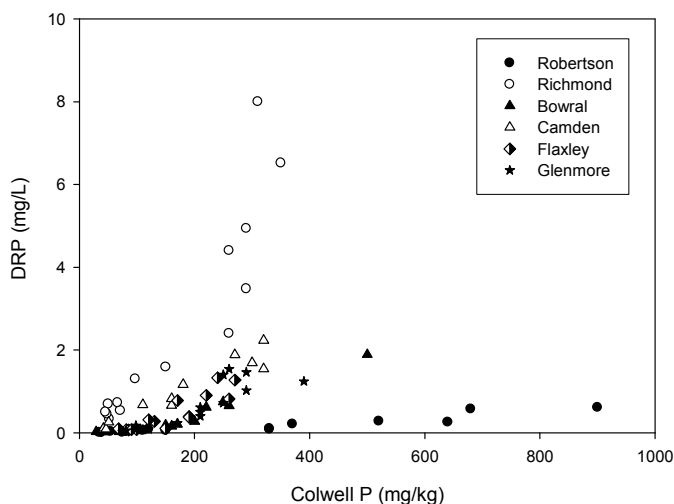


Figure 1. The relationship between Colwell P (0-1cm) and runoff DRP for six soil types ranging in P sorption capacity.

We subsequently used our results, a previously determined relationship between soil P 0-1 cm and 0-10 cm (Murray Hart pers comm.) and rainfall simulation and field scale runoff P concentrations (Dougherty *et al.* 2008) to model the effect of soil PBI and multiples of the agronomic soil P optimum (0-10 cm) on field scale runoff P concentration (Figure 2).

The modelled relationships in Figure 2 show that efforts should be made to constrain available P to the agronomic range to limit excessive concentrations of P in runoff, particularly for soils with PBIs <200. Farmers on soils with high PBIs, such as >1500, will have relatively minor water quality impact from P in runoff but should still actively manage their P inputs to minimise costs associated with wasted nutrient inputs and minimise any slight potential environmental impact.

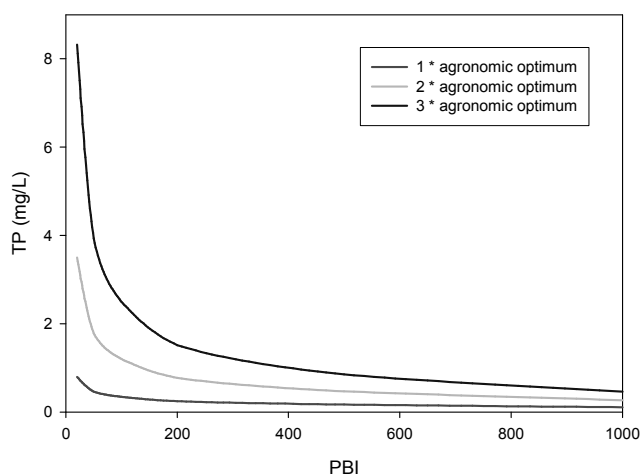


Figure 2. The modelled relationship between PBI (0-10 cm) and runoff TP for multiples of the agronomic optimum.

Conclusion

Routine measures of soil P status such as Colwell P are poor predictors of runoff P concentration. However, combining Colwell P values with information on soil P buffering provides a means of predicting runoff P concentrations. The large range of soil properties represented in this study, the careful preparation of the soils and the shallow sampling depth (0-1 cm) allowed these principles to be demonstrated. Extension to the field, with its intrinsically greater variability is yet to be demonstrated; nonetheless, it is clear that P additions to soils with low P buffering disproportionately increase runoff P concentration; consequently, such sites should be a priority for improved P management to reduce environmental risk.

References

- Anon (2002) National Research Project for Simulated Rainfall - Surface Runoff Studies. SERA 17.
- Barrow NJ, Bolland MDA, Allen DG (1998) Effect of previous additions of superphosphate on sorption of phosphate. *Australian Journal of Soil Research* **36**, 359-372.
- Burkitt LL, Gourley CJP, Sale PWG (2002) Changes in bicarbonate-extractable phosphorus over time when P fertiliser was withheld or reapplied to pasture soils. *Australian Journal of Soil Research* **40**, 1213-1229.
- Burkitt LL, Sale PWG, Gourley CJP (2008) Soil phosphorus buffering measures should not be adjusted for current phosphorus fertility *Australian Journal of Soil Research* **46**, 676-685.
- Dougherty WJ, Nicholls PJ, Milham PJ, Havilah EJ, Lawrie RA (2008b) Phosphorus fertilizer and grazing management effects on phosphorus in runoff from dairy pastures. *Journal of Environmental Quality* **37**, 417-428.
- Gourley CJP, Melland AR, Waller RA, Awty IM, Smith AP, Peverill KI, Hannah MC (2007) Making better fertiliser decisions for grazed pastures in Australia. Victorian Department of Primary Industries, Ellinbank.
- Isbell RF (1997) *The Australian Soil Classification*, CSIRO Publishing, Melbourne, Victoria.
- Murphy J, Riley JP (1962) A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* **27**, 31-36.
- Robertson FA, Nash DM (2008) Phosphorus and nitrogen in soil, plants, and overland flow from sheep-grazed pastures fertilized with different rates of superphosphate. *Agriculture Ecosystems and Environment* **126**, 195-208.

Triple superphosphate placement affects early growth of chickpea

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Abstract

Fertilizer placement with and close to the seed may have inhibitory effects on early growth of plants. In a pot study, chickpea (*Cicer arietinum* L.) root growth and nodulation was assessed by placing triple superphosphate (TSP) with seed (0) and 2 or 5 cm directly below the seed and in a control (TSP mixed thoroughly with the top 10 cm of soil) using a sand and a clay loam soil. Phosphorus fertilizer with and close to the seed produced necrotic symptoms in the lower leaves and reduced total root length, root surface area and nodule dry weight in sand. In clay loam there was no specific response of banding TSP, but most measured parameters were lower in the 0 and 2 cm treatments. TSP banding with and close to (<5 cm) the seed inhibited early growth of chickpea, especially in sandy soil, but less so in clay loam soil.

Keywords

Banding, fertilizer placement, minimum tillage, phosphorus, rice-based cropping system, toxicity

Introduction

In Bangladesh, chickpea is grown under rainfed conditions relying mostly on residual soil moisture after rainy season rice (*t. aman*). In the High Barind Tract (HBT) of northwest Bangladesh, power tillers have increasingly replaced bullocks for tillage, and can rapidly cover a large area for timely sowing of chickpea. However, the shallow and excessive cultivation by the rotary power tiller hastens evaporation of top soil moisture and makes chickpea more prone to terminal drought. To overcome these constraints, power tiller mounted minimum tillage planters (strip till) are under development.

Reduced fertilizer use efficiency is a common phenomenon in dry topsoil, particularly for phosphorus (P) fertilizer. Minimum tillage planters place seed and P fertilizer, triple superphosphate (TSP), together in a narrow slot of moist soil aiming to increase fertilizer use efficiency and nutrient uptake in the early growth of chickpea. However, there is a concern that TSP placed close to seed will inhibit emergence and establishment of chickpea seed, as reported previously for phosphorus fertilizers (MAP, DAP) in other species (Moody *et al.* 1995; Zhang and Rengel 1999). Zhang and Rengel (1999, 2000) reported in wheat that increased NH_4^+ and P concentration close to the developing seed may suppress early growth including root growth. Fertilizer toxicity in wheat with DAP was avoided if it was banded away from the seed (Jarvis and Bolland 1991; Zhang and Rengel 2000). In a preliminary glasshouse study, TSP placed with the seed reduced root length significantly in a sandy soil; in clay soil, P reduced root length in 12 days-old chickpea. In this study, it was hypothesised that early growth depression due to seed-placed TSP would be alleviated by banding it away from the seed.

Materials and Methods

Plants were grown in PVC columns of 30 cm height and 15 cm diameter containing 7 kg each of sand (yellow sand; $\text{pH}_{\text{CaCl}_2}$ 4.97) or clay loam soil (topsoil from Merredin; $\text{pH}_{\text{CaCl}_2}$ 6.63). Basal salts of nutrients were mixed as described in Bell *et al.* (1989) in sieved (4 mm mesh) soil. From the bottom, 18.5 cm of each column was filled with air dried soil. A further 10 cm was filled up after amendment with basal salts and TSP according to treatments.

Treatments: Granular TSP required per seed (0.15 g) was calculated based on the recommended broadcast dose for chickpea (100 kg/ha, i.e. 20 kg P/ha) in the HBT and the row spacing (40 cm). The placement distances were 0 (TSP mixed with a 2 cm layer of soil around seeds), 2 and 5 cm directly below the seed where TSP was mixed with a 2 cm layer of soil. A control treatment was included in which TSP was thoroughly mixed in the top 10 cm of soil to simulate broadcasting and ploughing in the field. Seed was placed 3 cm below the surface. Each treatment had three replications.

Growing and harvesting of plants: *Rhizobium* (Nodular, Group-N) suspension (@ 100 g/L water) was applied @ 1 mL/seed under the seed just before sowing. Twelve seeds of *desi* chickpea cv Genesis 836 were sown per column on 1 August 2009 and the columns kept in a glasshouse with 26/9 °C day/night temperature. Watering was done just after sowing, and every alternative day by weighing the soil to maintain water at field capacity (clay 14 % and sand 8 %). Harvesting was done at 24 days after sowing (DAS). Roots were washed under gently running water on a sieve (<0.5 mm) to prevent root loss. Nodules were counted and separated from the root and washed roots were assessed for root length and surface area using a scanner controlled by WinRhizo software (Regent Instruments, Quebec, Canada). Plant materials were dried in a forced-draft oven at 65 °C for 72 hrs and weighed.

Statistical analysis: Data were analyzed by Analysis of Variance (ANOVA) following a completely randomized design (CRD) by Statistix 8 software. Least significant difference (LSD) was used to test differences between treatment means.

Results

In sand, total root length in 0 and 2 cm treatments and root surface area in 0 cm was significantly reduced compared to 10 cm mixing treatment (Table 1). Although there was no significant difference in root and shoot dry weight, highest values were also observed in the 10 cm mixing treatment. Nodule dry weight was significantly reduced in 0 cm due to both smaller size (visual observation) and reduced number. Phosphorus toxicity symptoms (grayish white necrosis) were observed in lower leaves in 0 and 2 cm at 10 DAS; and in some plants of 5 cm and even in few plants of 10 cm mixing treatments at 13 DAS.

Table 1. Effect of triple superphosphate banding on the growth of chickpea at 24 days after treatment.

TSP placement below seed	Total root length (cm)	Root surface area (cm ²)	No. of nodules	Dry weight (mg)		
				Root	Shoot	Nodule
<i>Sandy soil</i>						
0	516	110	9.6	68.0	122	11.4
2 cm	513	112	9.5	68.4	119	14.2
5 cm	528	112	12.	68.5	122	16.8
10 cm mixing	571	122	11.8	74.2	135	17.0
CV	4.9	4.9	21.9	9.9	8.9	19.7
LSD (P=0.05)	49.3	10.5	ns	ns	ns	5.5
<i>Clay soil</i>						
0	431	88	29.3	52.2	205	7.8
2 cm	379	80	27.8	49.4	200	5.5
5 cm	462	95	27.6	53.6	209	8.3
10 cm mixing	436	91	31.3	55.8	230	6.2
CV	10.2	9.5	15.8	10.1	6.7	32.2
LSD (P=0.05)	82.1	ns	ns	ns	26.5	ns

ns- not significantly different (P < 0.05)

In clay loam soil, banding TSP with seed (0 cm banding) produced similar root, nodule and shoot growth to 10 cm mixing treatments (Table 1). Indeed, there was no effect of P fertilizer placement on root dry weight, root surface area, nodule number and dry weight. Shoot dry weight and root length were greater in 10 cm mixing treatment than 2 cm banding.

Discussion

In sand, the suppression of emergence when P was banded with the seed (0 cm) might be due to the osmotic effect of fertilizer which limits moisture uptake by the germinating seed. As P fertilizers have relatively lower salt index (SI) than nitrogen and potassium fertilizers (Mortvedt 2001), and TSP has a lower SI value than that of mono and diammonium phosphate, the final emergence was not reduced (data not shown). In field grown lupin in light textured soil, superphosphate banded with the seed reduced plant density and early growth due to high concentration of P and/or salt and the consequence of high osmotic pressure close to seed

(Jarvis and Bolland 1991). Superphosphate (Jarvis and Bolland 1991) and DAP (Zhang and Rengel 2002) toxicity happens only in the early growth stages, with symptoms generally disappearing with time and during more advanced stages of plant growth.

Toxicity symptoms in the terminal leaflets of the oldest leaf are a feature common to all salt toxicities (Greenway 1962). This might result more from the deleterious effects of excess salts within the tissues than from specific toxicity of accumulated phosphate ions (Bhatti and Loneragan 1970). Miller *et al.* (1970) suggested that DAP-related growth reduction was due to Ca deficiency caused by precipitation of Ca-P complexes.

Although there were no symptoms in plants grown in clay loam soil throughout the experimental period, decreased root length in 2 cm banding treatments (significantly less than in 10 cm mixing) might be due to an adverse effect of TSP in the root environment. This result is in accordance with Bhatti and Loneragan (1970) who found that severe depression of root growth in wheat starts before appearance of any symptom in the shoots even though their study was in siliceous sand. Just after emergence of the radical, the tender tip is inhibited in elongation when it encounters the concentrated fertilizer bands, which are not present when TSP is mixed in the top 10 cm of soil. However, after sowing, strong crusts formed on the top of every column of clay loam soil, some of which cracked. Crusting and variable cracking may have confounded the P placement effects on emergence and early growth especially in the 2 cm treatment.

Decreased root length in 0 and 2 cm banding depth especially in sand suggests that banding P fertilizer with and close to seed created toxicity. Blanchar and Caldwell (1966) found that oat roots did not grow in to a monocalcium phosphate (MCP) band. Also, Ouyang *et al.* (1998) reported that root growth stopped in the vicinity of a band containing urea and triple superphosphate (TSP). Actually, they used TSP as an ameliorating compound against NH_4^+ toxicity from urea. Trapeznikov *et al.* (2003) showed in wheat that shorter roots with more laterals grew in the nutrient-rich patch, while longer roots were observed where the same amount of nutrients (NPK compound fertilizer 11:10:11) was thoroughly mixed with the soil. They anticipated that ABA produced in the root due to increase in nutrient concentration reduced root elongation, since ABA is known to inhibit root elongation of well-watered maize seedlings (Sharp and Le Nobble 2002). Increased root length in the 5 cm banding treatment in both soils may be due to avoidance of salt toxicity and increased P fertilizer efficiency. Jarvis and Bolland (1990, 1991) found that banding superphosphate 5-8 cm below lupin seed avoids P toxicity problems.

Conclusion

From these results it is concluded that application of TSP with the seed and banding at 2 cm in sand is risky for seed emergence and early growth. In sand, a banding distance >5 cm seems necessary but it still has some suppressive effect on early growth. In clay loam soil, the recommended dose of TSP (100 kg/ha) was less toxic, with only marginal effects observed on emerged seedling growth. Thus banding of TSP directly with seed in the silty clay HBT soils in strip tillage is not likely to result in toxicity to chickpea. However, the dose of 100 kg/ha has been established for hand broadcast seed and fertilizer. Placement of TSP adjacent to the seed, as in strip tillage, may increase fertilizer use efficiency, and thus a reduced rate could meet the P needs of the crop. Our field study in a silty clay soil in the HBT in the 2008-09 season suggested that grain yield at 100 kg TSP/ha was not significantly different to that at 50 kg TSP/ha, but further confirmatory studies are required.

References

- Bell RW, McLay L, Plaskett D, Loneragan JF (1989) Germination and vigour of blackgram (*Vigna mungo* (L.) Hepper) seed from plants grown with and without boron. *Australian Journal of Agricultural Research* **40**, 273-279.
- Bhatti SA, Loneragan JF (1970) The effect of early superphosphate toxicity on the subsequent growth of wheat. *Australian Journal of Agricultural Research* **21**, 881-892.
- Blanchar RW, Caldwell AC (1966) Phosphate-ammonium-moisture relationships in soils: ion concentration in static fertilizer zones and effects on plants. *Soil Science Society of America Proceedings* **30**, 39-43.
- Greenway H (1962) Plant response to saline substrates. I. Growth and ion uptake of several varieties of *Hordeum* during and after chloride treatment. *Australian Journal of Biological Sciences* **15**, 16-38.

- Jarvis RJ, Bolland MDA (1990) Placing superphosphate at different depths in the soil changes its effectiveness for wheat and lupin production. *Fertiliser Research* **22**, 97-107.
- Jarvis RJ, Bolland MDA (1991) Lupin grain yields and fertilizer effectiveness are increased by banding superphosphate below the seed. *Australian Journal of Experimental Agriculture* **31**, 357-366.
- Miller MH, Mamaril CP, Blair GJ (1970) Ammonia effects on phosphorus absorption through pH changes and phosphorus precipitation at the soil root interface. *Agronomy Journal* **62**, 524-527.
- Moody PW, Edwards DG, Bell LC (1995) Effect of banded fertilisers on soil solution composition and short-term root growth. 2. Mono-ammonium and di-ammonium phosphates. *Australian Journal of Soil Research* **33**, 689-707.
- Mordvedt JJ (2001) Calculating salt index. *Fluid Journal* Spring, 1-3.
- Ouyang DS, McKenzie AF, Fan M (1998) Phytotoxicity of banded urea amended with triple superphosphate and potassium chloride. *Agronomy Journal* **90**, 734-739.
- Sharp RE, Le Nobble ME (2002) ABA, ethylene and the control of shoot and root growth under water stress. *Journal of Experimental Botany* **53**, 33-37.
- Trapeznikov VK, Ivanov II, Kudoyarova GR (2003) Effect of heterogeneous distribution of nutrients on root growth, ABA content and drought resistance of wheat plants. *Plant and Soil* **252**, 207-214.
- Zhang XK, Rengel Z (1999) Gradients of pH, ammonium, and phosphorus between the fertilizer band and wheat roots. *Australian Journal of Agricultural Research* **50**, 365-373.
- Zhang XK, Rengel Z (2000) Role of soil pH, Ca supply, and banded P fertilizers in modulating ammonia toxicity to wheat. *Australian Journal of Agricultural Research* **51**, 691-699.
- Zhang XK, Rengel Z (2002) Temporal dynamics of gradients of phosphorus, ammonium, pH, and electrical conductivity between a di-ammonium phosphate band and wheat roots. *Australian Journal of Agricultural Research* **53**, 985-992.

Using GIS approach to map soil fertility in Hyderabad district of Pakistan

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Abstract

A study was conducted in district Hyderabad of Pakistan to map the soil fertility using GIS software under different agricultural practices. Cotton, wheat and sugarcane are the major crops cultivated in the region. Due to arid climate, irrigated agriculture in the region depends largely on water withdrawal from Indus River while some farmers use tube-wells. Key characteristics of the region are intensive cropping, imbalanced use of fertilizers, unreliable and poor quality of the irrigation water which resulted in less fertile soils. However, there is yet no detailed spatial information with respect to the status of the micro and macro nutrients in the soils. The objective of this study was thus to prepare detailed maps using GIS for the soil fertility of the region and to link the status of fertility with agricultural practices. The soil samples were taken from 80 spatially distributed locations from a depth of 0-60 cm. Soil samples were analyzed for texture, electrical conductivity, pH, total nitrogen, available phosphorus, potassium and micro nutrients (Zn, Cu, Fe, Mn and B). The data regarding fertilizer application, cropping pattern, crop rotation and irrigation practices were also collected from the farmers. The interpolated maps for the status of micro and macro nutrients show a clear deficiency of nutrients across the district. Nitrogen is deficient in 96 %, potassium and phosphorus are below the critical levels in 95 and 76 % of the soils of the irrigated area, respectively. Organic matter is below recommended levels in 95 % of the cropping area. More than 50 % of the area has sandy loam to sandy clay loam soil texture. The cotton-wheat rotation does not provide any time for soil recovery and therefore intensive cropping followed by mismanaged heavy irrigation and insufficient and unbalanced fertilization caused nutrient deficiencies in the soils of this region.

Key Words

Soil Fertility, cropping pattern, Hyderabad.

Introduction

Until 2025, food production must grow by at least 40% to meet the needs of a 33% increase in population and to satisfy the trends for improved nutrition (Bos *et al.* 2005). To meet these targets of food production for an affluent population, the increase in food grain and hence the improvement in agriculture sector is inevitable. As land is finite, increased food production from the limited land resources is one of the tasks for the coming decades. Moreover, farmers apply fertilizers without having knowledge of the status of the nutrients in their soils. Agriculture, being the backbone of Pakistan's economy, contributes approximately one-fourth of the country's gross domestic product (GDP) and employs almost half of its labor force. Due to intensive cropping systems, imbalanced use of fertilizer, unreliable and poor quality of irrigation water, the soils of the study region are reported as less fertile (than what?) (NFDC-FAO 2006a; Rashid and Ryan 2004; Rashid *et al.* 2006). Due to lack of knowledge and institutional incapability to implement the developed norms, farmers apply heavy fertilizer doses without considering the current nutrient status of their soils. Therefore, farmers need to be aware of the nature and severity of the nutrient problems in order to arrive at a prudent decision regarding the kind and dose of fertilizer to be applied (Rashid and Rafique 1998; Rashid and Ryan 2004). The district of Hyderabad is one of the leading agricultural production regions of Pakistan. Cotton-wheat is a dominant cropping pattern with intensive irrigation to meet the cropping requirements in an arid climate. Large farms mainly produce mono crops (e.g. mango), whereas the medium and small farms are intercropping wheat with sugarcane besides the wheat-cotton in rotation. Cultivation of wheat with onion is also a common practice within the region.

Despite the importance of the region in the agricultural sector, there is still no detailed spatial information showing the nutrient status of soils. The objective of the study was thus not only to prepare detailed maps of soil fertility of the region but also to link the status of fertility with agricultural practices and the nutrient status of crops by DRIS and critical level (CL) approaches to identify the most important nutrient constraints for a sustainable production (DRIS and CL will be published elsewhere).

Materials and Methods

This study was conducted during the 2007-08 vegetation season in the district of Hyderabad, located at 25.367°N latitude and 68.367°E longitude with an elevation of 13 m from mean sea level. The soils of the study area are light to medium and some parts of the region are heavy in texture. Composite soil samples from eighty locations distributed randomly across the whole of the district were collected at the depth of 0-60 cm. The soil samples were air-dried and ground to pass a 2 mm sieve for the analysis of soil pH, OM and macronutrients (N, P and K) and micronutrients (Cu, Zn, Fe, Mn and B).

Soil pH was determined with a pH electrode at a soil to water ratio of 1:2.5 (w/v) (Lu 1999). Soil OM was analyzed using the Walkley–Black method (Walkley and Black, 1934). Because the soil was calcareous, available Zn, Cu, Mn, and Fe were extracted by the DTPA procedure developed for calcareous soils (Lindsay and Norvell 1978), extracting 10 g soil (<2 mm) with 20 mL of 0.005 M DTPA + 0.01 M CaCl₂ + 0.1 M TEA (triethanolamine) solution. After 2 h continuous shaking at room temperature, the soil suspension was centrifuged and filtered through Whatman No.5 filter paper. Aliquots were analyzed by atomic absorption spectrophotometer to determine the amounts of available Cu, Zn, Mn, and Fe. The way points on the global positioning system (GPS) device were marked during the field work from the all eighty locations and imported to Arc GIS software. The geographical information system software Arc GIS was used to interpolate the results from the point data to the entire region. Kriging interpolation (Cressie 1992) was used for the estimation of the spatial distribution of nutrients.

Results and Discussion

The results of the spatially interpolated maps show that the distribution of macro and micro nutrients is generally low but varies across the district. Nitrogen is deficient in 96 % of the irrigated area, whereas potassium and phosphorus are below the critical levels in 95 and 76 % of the soils of the irrigated area, respectively. The low fertility of soils caused by low amounts of available nutrients can be due to several reasons. Aulakh and Singh (1997) reported that the low nutrients in the soils can be due to the low organic matter and coarse soil texture and therefore only adequate supply of nutrients can improve the productivity of soil. In the study area, more than 50 % of the irrigated area has a coarse soil texture and 95 % of the cropped area is low in organic matter. Although the low OM with coarse soil texture resulted in nutrient deficiency in the area, there are further important factors such as cropping history. The survey during the data collection revealed that farmers are using cotton-wheat rotation in more than 70 % of the area for a long time. Dwivedi *et al.* (2001), S.Fujisaka *et al.* (1994) and Singh and Singh (1995) documented that continuous cropping for longer periods with low system diversity, and often with poor crop management practices, resulted in loss of soil fertility due to emergence of multiple nutrient deficiencies due to nutrient mining, especially if not compensated for by addition of proper fertilizer amounts in the required ratios.

Conclusion

The maps suggested that there are overall multi-nutrient deficiencies in the region. The reasons for low fertility are the intensive cropping system, imbalanced use of fertilizer and thus nutrient mining, possibly of minor elements such as Zn. The cotton-wheat rotation is intensively being used in the area and is causing the low fertility of soils when nutrient and OM supply are not compensating for the losses. One of the solutions could be the introduction of leguminous species into the cotton-wheat rotation either by intercropping with the leguminous crops or growing leguminous crops in between the season. The benefits of legume crops have been reported repeatedly (Buresh and Datta 1991; Singh *et al.* 2002; Timsina and Connor 2001). Balanced fertilizer use and complementary use of organic nutrient inputs with fertilizers are the possible agro-techniques to sustain yield, increase fertilizer use efficiency and to restore soil fertility under intensive cropping (Dwivedi *et al.* 2003; Timsina and Connor 2001; Yadav *et al.* 1998a).

References

- Rashid A, Rafique E (1998) 'Micronutrients in Pakistan Agriculture: Significance and Use'. (Pakistan Agriculture Research Council: Islamabad).
- Aulakh MS, Singh B (1997) Nitrogen losses and fertilizer use efficiency in irrigated porous soils. *Nutr. Cyc. Agroecosyst* **47**, 197–212.
- Behera SK, Panda RK (2009) Integrated management of irrigation water and fertilizers for wheat crop using field experiments and simulation modeling. *Agricultural Water Management*(96): 1532–1540.
- Bos MG, Burton MA, Molden DJ (2005) 'Irrigation and Drainage Performance Assessment: Practical Guidelines'. (CABI Publishing: Trowbridge, US).

- Buresh RJ, Datta SKD (1991) Nitrogen dynamics and management in rice–legume cropping systems. *Adv. Agron* **45**, 1–59.
- Cressie N (1992) ‘Statistics for Spatial Data’. (Wiley: New York).
- Dwivedi BS, Shukla AK, Singh VK, Yadav RL (2001) Results of participatory diagnosis of constraints and opportunities (PDCO) based trials from the state of Uttar Pradesh Bhopal, India. In ‘Development of Farmers’ Resource-Based Integrated Plant Nutrient Supply Systems: Experience of a FAO-ICAR-IFFCO Collaborative Project and AICRP on Soil Test Crop Response Correlation’. (Eds A Subba Rao, S Srivastava) pp. 50–75. (IISS)
- Dwivedi BS, Shukla AK, Singh VK, Yadav RL (2003) Improving nitrogen and phosphorus use efficiencies through inclusion of forage cowpea in the rice–wheat system in the Indo-Gangetic plains of India. *Field Crops Res.* **84**, 399–418.
- Lindsay WL, Norvell WA (1978) Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Am. J.* **42**, 421–428.
- Lu RK (1999) ‘Analysis Methods of Agricultural Chemistry’. (Agricultural Science Press: Beijing).
- NFDC-FAO (2006a) ‘The impact of deregulation on the fertilizer sector and crop productivity in Pakistan’. (National Fertilizer Development Center: Islamabad, FAO, Rome).
- Rashid A, Rafique E (1998) ‘Micronutrients in Pakistan agriculture: Significance and Use’. (Pakistan Agriculture Research Council: Islamabad).
- Rashid A, Ryan J (2004) Micronutrient constraints to crop production in soils with Mediterranean-type characteristics: A review. *Plant Nutrition* **27**, 959–975.
- Rashid A, Yasin M, Ali MA, Ahmed Z, Ullah R (2006) An alarming boron deficiency in calcareous rice soils of Pakistan: Boron use improves yield and cooking quality. In ‘Proceedings: 3rd annual symposium on all aspects of plants and animal boron nutrition, Wuhan, China, 9–13 sep 2005’. (Springer: New York).
- Fujisaka S, Harrington L, Hobbs P (1994) Rice–wheat in South Asia: systems and long-term priorities established through diagnostic research. *Agric. Syst.* **46**, 169–187.
- Singh BVK, Sharma BB, Dwivedi BS (2002) The impact of diversification of a rice–wheat cropping system on crop productivity and soil fertility. *J. Agric. Sci.* **139**, 405–412.
- Singh J, Singh JP (1995) Land degradation and economic sustainability. *Ecol. Econ.* **15**, 77–86.
- Timsina J, Connor DJ (2001) Productivity and management of rice–wheat cropping systems: Issues and challenges. *Field Crops Res* **69**, 93–132.
- Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29–38.
- Yadav RL, Dwivedi BS, Prasad K, Gangwar KS (1998a) Overview and prospects for enhancing residual benefits of legumes in rice and wheat cropping systems in India. In ‘Residual Effects of Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain’. (Eds JVDK Rao, D Johansen, TJ Rego) pp. 207–225. (Oxford/IBH: New Delhi, India)

Using the soil as a buffer allows more sustainable management of nitrogen in sugarcane production

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Abstract

Nitrogen (N) fertiliser management is increasingly important in sugarcane as imperatives to reduce environmental impacts of N escalate. In this paper we report testing of a new concept for N management in sugarcane, the N Replacement system. This system relies on soil N reserves to buffer differences in crop N needs and N fertiliser supply in individual crops, and so aligns N applications with *actual* cane production rather than *potential* production. In five experiments conducted over four crops, total sugar yields in the N Replacement treatment were similar to those achieved with the farmers' conventional N management even though average N applications were 36% lower. N lost to the environment was estimated to be reduced by 62%. The results imply that N buffering was adequate in the soils which spanned a wide range of carbon (C) levels (0.8-2.1%). We conclude that the ecologically-based N Replacement system may deliver superior environmental outcomes without significantly reducing production for sugarcane, and other semi-perennial crops in the tropics and subtropics.

Key Words

Immobilisation, Mineralisation, Environmental impact, Organic matter, N Replacement.

Introduction

Controlling N losses from cropping systems is important because of the impacts of N on human health and ecosystems (predominantly as NO₃⁻) and its role in contributing to climate change (through N₂O emissions). These are challenging issues for sugarcane, which requires high applications of N fertiliser for commercial production (Roy *et al.* 2006) and is increasingly used for biofuels (Macedo *et al.* 2008). It is possible that traditional N fertiliser recommendations for sugarcane will not meet these challenges. Recommendations in many countries are based on potential or expected crop yields (e.g. Schroeder *et al.* 2006) and so result in over-application of N is the common situation, as *actual* production is often less than potential.

Sugarcane is a deep rooting semi-perennial crop (i.e. it is allowed to ratoon a number of times after annual harvesting) grown in subtropical and tropical areas where soil N cycling is often rapid. This rapid N cycling allows large amounts of N to be immobilised and subsequently mineralised over the long term (Ng Kee Kwong *et al.* 1984; Meier *et al.* 2006), where it can be efficiently retrieved by the deep root system (Thorburn *et al.* 2003). In effect, the soil may be able to act as a good buffer for N – absorbing N fertiliser additions by immobilisation and subsequently making this N available through mineralisation. If so, sugarcane may be well suited to an ecologically-based approach to N management (Drinkwater and Snapp 2007), where N fertiliser applications are geared to maintaining soil N stores. These soil N stores can then provide the crop's N needs, rather than more directly 'feeding' the crop with fertiliser N.

Such an ecologically based N management system, known as N Replacement, was proposed for sugarcane by Thorburn *et al.* (2004). They linked N applications to crop N off-take in the previous crop. The assumption was that, if the yield of the coming crop was larger than that of the previous crop, additional N requirements would be supplied from soil N stores. Conversely, these N stores would be 'topped up' when a small crop followed a large one. They suggested a potential saving in N fertiliser up to 40% compared with common N fertiliser applications in Australia, and consequently N lost to the environment may be reduced by 90%. In this paper we report on five field experiments established to test this concept over four crops in the diverse soils and climates of the Australian sugarcane industry.

Methods

Experiments were established on commercial farms in 2003 or 2004 to compare the N Replacement (NR) system with the farmers' conventional N fertiliser management (NF) over four crops. Farms were located in

the wet tropics around Cairns (~16°S - Mulgrave and Innisfail, Table 1), the dry tropics near Townsville (~19°S - Burdekin), and the sub-tropics at Bundaberg (~25°S to 28°S). Crops at sites BK-1, BK-2 and BU-1 were irrigated and the others rainfed. Crops at sites BK-1 and BK-2 were burnt at harvest. Others were harvested unburnt with all residues retained on the soil surface. The amount of N fertiliser (kg/ha) applied in the NR approach was targeted to be 1 kg N/t cane harvested in the previous crop where residues were retained and 1.3 kg N/t cane where the crop was burnt (Thorburn *et al.* 2004, 2010). This is less than current recommendations, either in Australia (Schroeder *et al.* 2006) or more generally (Roy *et al.* 2006).

Table 1. Details of soils at the experimental sites and the average N fertiliser applied and N lost to the environment (both kg/ha/crop) in different treatments (NR-N Replacement; NF-N Farm).

Site code	Region	Soil texture 0-0.6 m	Soil C 0-0.3 m (%)	Soil C/N 0-0.3 m	N applied		Environmental losses of N	
					NR	NF	NR	NF
BK-1	Burdekin	sandy clay loam	0.77	14.2	159 ^a	318 ^a	2	194
BK-2	Burdekin	sandy clay loam	0.84	15.3	217 ^a	326 ^a	107	231
BU-1	Bundaberg	sandy loam to sandy light clay	0.75	14.8	95	140	45	93
IN-3	Innisfail	light clay	2.16	16.6	117	144	74	87
ML-1	Mulgrave	sandy clay	1.17	16.9	135	180	69	123

^a N applications include substantial N applied through nitrate contained in irrigation water.

The sites had been managed using the farmers' normal practice prior to the experiments, except at BU-1, where the experiment was established in the first ratoon crop of a pre-existing N rate experiment (Thorburn *et al.* 2003). In this experiment the NR treatment was applied to plots that had received **no** N fertiliser in the preceding plant crop (yielding 83 t/ha). The experiments were managed by the farmers using their normal practice so that yields were representative of commercial production, not research station experiments.

The experimental layout at each farm was decided jointly with collaborating farmer groups. Three experiments (BK-1, BK-2 and BU-1) were established as randomised designs with treatments replicated, while the other two were non-replicated demonstration experiments. Plots were large enough to allow harvested cane yield, cane sugar content and, hence, sugar yield to be determined from commercial harvesting and milling operations. The amount of N lost to the environment over the whole experiment was estimated for each treatment as the difference between N applied and that (1) lost through crop harvest and, where applicable, residue burning, and (2) change in soil mineral N (assuming no change in organic N). The amount of N in the crop and trash was determined from mass and N concentration in the harvested cane and residue measured at harvest. Soil N was measured (to 2 m) at the start of the experiments and after harvest. In 2007, soils (0-0.3 m) were also analysed for total C and 'labile C' (i.e. C oxidised by 3.33 mM KMnO₄).

Results

Across the five sites, sugar yields were lower in the NR treatment than the NF in the first and second crops, but higher in the third and fourth crops (Figure 1). However, yields increased in the NR treatment relative to NF in subsequent crops so that cumulative sugar yields were similar in the two treatments over the four crops (Figure 2), and with an average improvement across all sites of 0.16 t/ha in the NR treatment. Yields in the NR treatment were achieved at substantially lower N inputs (an average of 80 kg/ha/crop; Table 1) than the NF treatment and so the N use efficiency in the NR treatment (i.e. slopes of the lines in Figure 2) was higher.

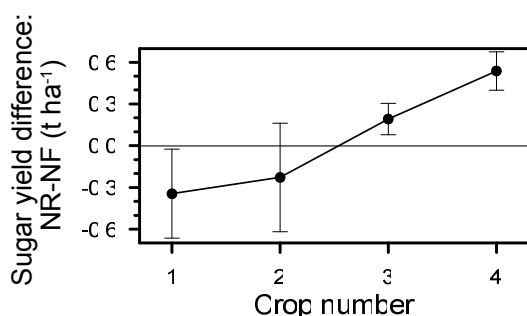


Figure 1. Difference in sugar yield between the NR and NF treatments for each crop harvested averaged across the five experiments. Error bars indicate ± 1 standard error.

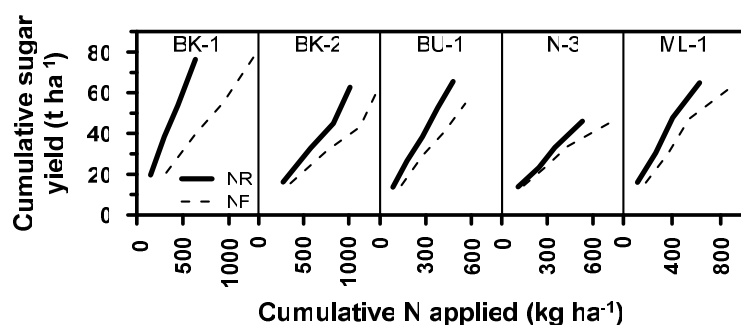


Figure 2. Cumulative sugar yields as a function of cumulative N fertiliser applications for the NR and NF treatments at each experiment.

Despite the lower N inputs and similar sugar production in the NR treatments, there was no evidence of soil organic matter rundown. Total C and labile C (expressed either per mass of soil or as a fraction of total C) were similar in both treatments (Table 2). Similarly, there was generally no evidence that soil mineral N (SMN) was rundown (to 2 m soil depth) through time (e.g. Site BU-1, Figure 3), except at site IN-3 (Figure 3). There, SMN decreased by 18.3 kg/ha/crop (i.e. the slope of the line in Figure 3) during the experiment in the NR treatment compared with an average increase of 0.5 kg/ha/crop in the NF treatment. Hence there was a relative reduction in SMN of 18.8 kg/ha/crop in the NR treatment relative to NF. At the other sites, SMN decreased in the NR treatment relative to NF by 2.1 and 2.5 kg/ha/crop at the BU-1 and ML-1 sites, respectively, and increased by up to 44 kg/ha/crop at sites BK-1 and BK-2.

Table 2. Average total C (TC), labile C (LC) and LC as a proportion of TC (LC/TC) in soils sampled from sites at harvest in 2007 for the NR and NF treatments. Standard errors are shown in parenthesis.

	Total C (%)	Labile C (%)	LC/TC
NR	1.4 (0.2)	0.11 (0.01)	0.073 (0.004)
NF	1.2 (0.1)	0.08 (0.01)	0.071 (0.004)

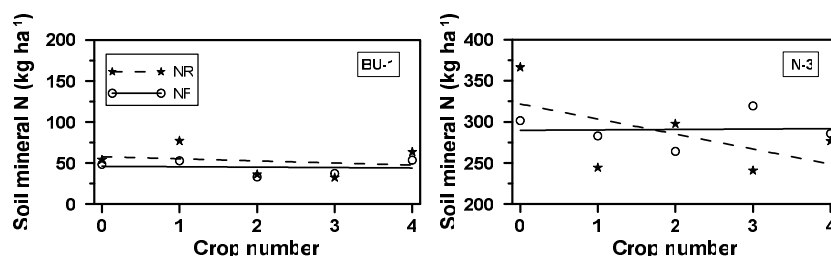


Figure 3. Soil mineral N (0.2 m depth) sampled at the start of the experiment (crop number = 0) and at harvest of the four successive crops. The legend applies to both panels.

N lost to the environment was between 87 and 231 (mean 146) kg/ha/crop in the NF treatment, but was reduced to between 2 and 107 (mean 59) kg/ha/crop in the NR treatment (Table 1). The highest losses occurred at sites BK-1 and BK-2 where substantial N was applied to the plots in irrigation water.

Discussion

Our results confirm that the N replacement concept has promise for meeting the productivity needs of N fertiliser management in sugarcane, while reducing potential environmental losses of N, as proposed by Thorburn *et al.* (2004). Total sugar production during the experiments was maintained (Figure 2) at substantially (36%) reduced N fertiliser inputs (Table 1). This result would increase farm profitability (through lowering input costs) and maintain sugar mill region profitability (which relies on total sugar production). The trend for yields to increase in the NR relative to the NF treatment over successive crops (Figure 1), which may be due to lower N applications enhancing root activity (Thorburn *et al.* 2003), suggest there is potential for the NR system to further enhance profitability of the sugar industry through time. The lower fertiliser inputs resulted in a >50 % decrease in the amount of N lost to the environment (Table 1). This decrease was not as great as that predicted by Thorburn *et al.* (2004) because N contained in sugarcane in the experiments was lower than predicted (Thorburn *et al.* 2010), allowing more N to be lost to the environment. While we have not assessed the relative magnitude of the different N loss pathways to the

environment (e.g., denitrification, leaching or runoff), a 50 % reduction in losses for any or all pathways would greatly enhance the sustainability of sugarcane production.

The results of these experiments also suggest that the philosophy of drawing on N reserves in the soil to buffer some of the short term differences between crop N needs and N supply from fertiliser is applicable in sugarcane production. This is a more complete view of soil N processes than used in some other recommendation systems, which focus only on N mineralisation (Schroeder *et al.* 2006). Buffering of N inputs to, and outputs from soils may be greater in soils with higher organic matter, so having greater capacity to immobilise and mineralise N. However, there was no difference in the relative performance of the NR treatment at sites with soils of low organic matter (e.g. BU-1) and those with substantially higher organic matter (IN-3), suggesting that high organic matter levels are not necessary to provide sufficient buffering for the NR system to be successful. In fact, the low organic matter soil at BU-1 was able to overcome the deliberate rundown of N in the NR plots prior to the experiment, resulting in similar total production in both N treatments.

There are several possible drivers for over-application of N to sugarcane. One is the concept of aligning fertiliser applications to potential yields (e.g. Meyer and Wood 1994; Schroeder *et al.* 2006). This clearly wastes fertiliser when actual yields do not realise their potential. It also overlooks the potential for stores of N in the soil to provide additional N to the crop over the short-term (e.g. a single crop). Yields in a crop can be 20-30% greater than those expected without being limited by N supply (Thorburn *et al.* 2010). Another driver of high N applications in sugarcane is the perception of high losses of N to the environment caused by high rainfall or irrigation. Our results in the wet tropics (Site IN-3, average rainfall of 3,600 mm/yr) and fully irrigated crops in the Burdekin show that while losses of N can be substantial (Table 1), they can be lowered considerably by reducing N rates. Hence high losses are more due to the high amounts of N applied in farmers' conventional practices than the environment itself. Thus a more ecologically-based approach to N management, focussing more on having fertiliser applications maintaining soil N stores (Drinkwater and Snapp 2007), may be the basis for sustainable management of N fertiliser in tropical and subtropical perennial and semi-perennial crops such as sugarcane. Further work to define the amount of N that needs to be replaced after each crop in the NR system would be valuable.

Acknowledgements

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References

- Drinkwater LE, Snapp SS (2007) Nutrients in agroecosystems-Rethinking the management paradigm. *Advances in Agronomy* **92**, 163-186.
- Macedo IC, Seabra JEA, Silva JEAR (2008) Greenhouse gas emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/06 averages. *Biomass and Bioenergy* **32**, 582-595.
- Meier EA, Thorburn PJ, Wegener MK, Basford KE (2006) The availability of nitrogen from sugarcane trash on soils in the wet tropics of North Queensland. *Nutrient Cycling in Agroecosystems* **75**, 101-114.
- Meyer JH, Wood RA (1994) Nitrogen management of sugar cane in South Africa. *Proceedings of the Australian Society of Sugar Cane Technologists* **15**, 93-104
- Ng Kee Kwong KF, Deville J, Cavalot PC, Riviere V (1986) Biological immobilization of fertilizer nitrogen in humid tropical soils of Mauritius. *Soil Science* **141**, 195-199.
- Roy RN, Finck A, Blair GJ, Tandon HLS (2006) 'Plant nutrition for food security: A guide for integrated nutrient management'. FAO Fertilizer and Plant Nutrition Bulletin 16 (FAO, Rome).
- Schroeder BL, Wood AW, Moody PW, Panitz JH, Sluggett RJ, Salter B (2006) Delivering nutrient management guidelines to growers in the central region of the Australian sugar industry. *Proceedings of the Australian Society of Sugar Cane Technologists* **28**, 142-154.
- Thorburn PJ, Horan HL, Biggs IM, Park SE (2004) Which is the most important crop when assessing nitrogen applications – the next or the last? *Proceedings of the South African Sugar Technologists Association* **78**, 383-391.
- Thorburn PJ, Dart IK, Biggs IM, Baillie CP, Smith MA, Keating BA (2003) The fate of nitrogen applied to sugarcane by trickle irrigation. *Irrigation Science* **22**, 201-209.
- Thorburn PJ, Webster AJ, Biggs JS, Biggs IM (2010) A new way to determine nitrogen fertiliser requirements of sugarcane crops to meet global environmental challenges. *Plant and Soil*, in press.

Utilization by plant cane, and first and second ratoon crops of nitrogen fertiliser applied at planting

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Abstract

Sugarcane, as a semi-perennial crop, depends on the nutrient stocks in the root system in order to support the initial growth of sprouts, and there is evidence of a direct relationship of these nutrient stocks with the management of nitrogen fertilization. However, there is little knowledge about the amount of N fertilizer applied in a crop season that can still be used by sugarcane in a subsequent crop season. In order to evaluate urea-N utilization by sugarcane in the plant cane crop season and its residual effect in subsequent ratoon crops, three experiments were carried out in the São Paulo State, Brazil, from February of 2005 to July of 2008. The experimental design was randomized complete blocks, with four treatments, being three rates of urea-N: 40, 80 and 120 kg N/ha applied in furrow at planting, and a control without N fertilizer. In the center of the plots with urea-N fertilization were installed microplots that received urea labeled with ¹⁵N. On average, the recovery by plant cane was about 80% of total N recovered in the three harvests. In the first and second ratoon crops the utilization was lower being around 15% and 5% of total N recovered respectively. These results showed that the nitrogen fertilization in a crop season also can be used by the crop in subsequent ratoons, and the amount recovered will depend on the crop management adopted, since the efficiency of nitrogen fertilization in this work, considering the three crop seasons, was low, about 35% of total N applied at planting.

Key Words

Saccharum spp, urea-¹⁵N, isotopic technique.

Introduction

In the literature, for the majority of studies regarding the response of sugar cane to nitrogen fertilization, both in plant cane and in ratoon cane, fertilizations were evaluated by the yield of the cycle (year/harvest) of the crop for which fertilization was made. In this sense, sugar cane has been considered as an annual crop, and rare are studies like those of Penatti *et al.* (1997) and Orlando Filho *et al.* (1999) which maintained the experimental plots for consecutive harvests in the field so as to evaluate the cumulative effect of fertilizations with N doses on the yield of plant cane and ratoon cane. Studies of this nature have shown this effect and have confirmed that the response of plant cane to nitrogen was reflected in greater vigor of the ratoon cane, increasing the yield in subsequent ratoon crops when comparing sugar cane with and without nitrogen fertilization. Vitti *et al.* (2007) observed a notable residual effect of nitrogen fertilization of the third ratoon for stalk yield of the subsequent ratoon (4th ratoon).

In this scenario, is it not the case to question regarding the possibility of nitrogen fertilization, both at planting and in ratoon cane, as being related to root growth and to the formation of a nutrient stock in the underground part of the crop with an effect on the yield accumulated in subsequent cuttings? In fact, Franco *et al.* (2007) noted that nitrogen fertilization at planting significantly increased the quantity of macronutrients in the plant cane reserve organs (roots and rhizomes).

On the other hand, there is still the question: is it possible that the nitrogen coming from fertilizer applied in the previous year is still being utilized by the sugar cane plants in the next agricultural cycle? To respond to this question, the use of nitrogen fertilizers labeled with ¹⁵N is necessary.

In these studies, the destination of a considerable part of the ¹⁵N-fertilizer (20% to 40%) applied to the sugar cane crop is the soil, where the nutrient is incorporated in the stock of N of the organic matter (Cantarella *et al.* 2007). Nevertheless, under Brazilian conditions, the results obtained under field conditions regarding recovery of residual ¹⁵N-fertilizer (applied in the previous agricultural cycle) by sugar cane in the subsequent cycle are practically non-existent.

Thus, the objective of this study was to evaluate the utilization of ¹⁵N-fertilizer applied at the planting of plant cane by the subsequent ratoons (residual effect), seeking better understanding of the causes of the responses of the sugar cane crop to nitrogen fertilization.

Material and Methods

Site description

The experiments were performed in three sugar cane producing areas located in the state of São Paulo, Brazil. The first belongs to the São Luiz Ethanol plant (SL), in Pirassununga county (Latitude 21° 55' 54''S, Longitude 47° 10' 54''W). The altitude is 650 m and the climate is Aw (Tropical Savanna, in the Köppen classification). The area has a slightly rolling slope (< 5%), and the soil is a Typic Eutruxox (Embrapa 2006). The sugar cane was planted from February 21-24, 2005. The second area, belonging to the Santa Adélia Ethanol plant (SA), is in Jaboticabal county (Latitude 21° 19.98' S, Longitude 48° 19.03' W). The predominant altitude in the region is 600 m, and the climate is Aw (Tropical savanna, in the Köppen classification). The area presents a slightly rolling slope (<5%), and the soil is a Arenic Kandiusults (Embrapa 2006). The sugar cane was planted from April 4-8, 2005. The third area, belonging to the São Martinho Ethanol plant (SM), is in Pradópolis county (Latitude 21° 15' S, Longitude 48° 18' W). The predominant altitude in the region is 580 m, and the climate is Aw (Tropical savanna, in the Köppen classification). The soil in this area is a Rhodic Eutruxox (Embrapa 2006). The sugar cane was planted from March 2-6, 2005.

Experimental design

Fertilizer treatments of the planted cane consisted of one of three doses of N (40, 80 and 120 kg/ha of N as urea) applied at the bottom of the planting furrow, plus one control without nitrogen fertilizer. These doses were chosen based on the recommendations of the Technical Bulletin 100 (Espironello *et al.* 1996), which recommends the application of up to 90 kg/ha of N at planting. The treatments were distributed in a randomized block design with four replications. The experimental plots were composed of 48 rows of 15 meters in length with a space between rows of 1.5 m. In the inside of each plot, a microplot was installed, with dimensions of 2 m in length and 1.5 m width (totaling 3 m²), which received urea labeled with ¹⁵N (excess of 4.67 % atoms of ¹⁵N). In the SM area only the treatment of 80 kg/ha was treated with the ¹⁵N labeled urea. The variety of sugar cane planted was SP81 3250, as it is highly adaptable and very productive and one of the varieties planted most in the Center-South region of Brazil. In all of the plots, at the bottom of the furrow, 120 kg/ha of K₂O and 120 kg/ha of P₂O₅ were applied as potassium chloride and triple superphosphate, respectively.

The plant cane was harvested around 16 months after planting (June, July and August of 2006, at SL, SA and SM respectively), with the experimental plots being maintained, applying only 150 and 60 kg/ha of K₂O and P₂O₅ respectively to all the plots. Harvest of the first ratoon was made 12 months after harvest of the plant cane. After the harvest of the first ratoon, the same doses of P and K were applied over the residual straw to all the plots, with the harvest of this crop undertaken at 24 months after the harvest of the plant cane.

Sampling

For evaluation of the utilization of the ¹⁵N-urea in the plant cane and first and second ratoon cycles, the plant shoots of the microplots were manually harvested in all the experiments (SL, SA and SM), and the roots only in the SL and SA areas. Harvest of the plants from the microplots with ¹⁵N-urea and also in the control, without nitrogen fertilization, was undertaken in 1m of the row, in the center and in contiguous positions in the rows adjacent to the microplot, separating samples of dry leaves, tips and stalks. In these samples, natural plant material mass was determined. All the material was chopped in a mechanical forage chopper. After grinding and homogenization of each moist sample, a subsample was removed, which was dried in a laboratory oven (65 °C), and the moisture content of this material was determined. The dry matter was ground in a Wiley mill and used in the determinations of total N and of ¹⁵N abundance (% of atoms of ¹⁵N) in a mass spectrometer ANCA/SL, model 20/20 from Europa Scientific, Krewe, U.K. The roots were evaluated only at the harvest of the plant cane, being collected by means of a 55 mm internal diameter probe in the center of the microplots. Sampling was made at a depth of 0-60 cm. The roots and rhizomes separated from the soil were washed in running water and also dried in a ventilated laboratory oven at 65 °C. The root dry matter was processed and analyzed in regard to total N content and abundance of ¹⁵N (% of atoms of ¹⁵N) in the same way as undertaken for the shoot samples.

Data analysis

The utilization of urea-¹⁵N by sugar cane was calculated according to equations:

$$(a) \text{ NDF} = [(A - C)/(B - C)] \cdot NT;$$

$$(b) \text{ R (\%)} = (\text{NDF}/\text{NAF}) \cdot 100$$

where NDF is the nitrogen in the plant derived from fertilizer; A is the abundance of ¹⁵N atoms in the plant;

B is the abundance of ^{15}N atoms in the fertilizer; C is the natural abundance of ^{15}N atoms (0.366%); NT is the total nitrogen of the aboveground part in kg N/ha; R - recovery of ^{15}N -fertilizer by sugar cane; NAF – nitrogen dose applied (kg/ha). (Hope these changes are correct!!)

Results

Utilization of the N-fertilizer (Tables 1 to 3) applied at the planting of the sugar cane field by the sugar cane crop was greater in the plant cane cycle, representing, in the mean of the areas, 80% of the total of N-urea recovered in the three crop cuttings. In spite of that, 15% of the total N-urea recovered throughout the three cycles was taken up by the plants of the first ratoon. This confirmed, in spite of the small quantities (around 3.0 kg/ha of N), that nitrogen fertilization presented a quantitative residual effect, and may therefore have an effect on crop yield in subsequent cuttings. In spite of not having worked with fertilizers enriched with ^{15}N , Penatti *et al.* (1997), Orlando Filho *et al.* (1999) and Vitti *et al.* (2007) observed this residual effect in field tests with nitrogen fertilization in plant cane and ratoon cane.

The results of N-fertilizer use by the second ratoon were only measured in the areas of SA and SM, keeping in mind that at SL there was an accidental fire which resulted in the results of this harvest being lost. At any rate, the results of the remaining areas (SA and SM) showed that the utilization by the second ratoon of the N-fertilizer applied at planting was very low, 42 months after its application.

Table 1. Utilization by sugar cane of urea- ^{15}N applied at planting. São Luiz Ethanol plant field

N Rates (kg/ha)	Planted Cane			Above ground Part	Roots	Entire Plant
	Stalks	Dry Leaves	Tips			
	kg/ha					
40	6,1 ± 0,7	3,2 ± 0,3	2,2 ± 0,2	11,5 ± 0,5	1,4 ± 0,4	12,3 ± 0,6
80	9,7 ± 1,8	5,9 ± 0,2	3,1 ± 0,8	18,7 ± 2,4	2,2 ± 0,5	20,0 ± 2,1
120	13,5 ± 1,3	6,7 ± 1,0	3,2 ± 1,1	23,4 ± 2,4	2,5 ± 0,8	24,9 ± 2,4
1st Ratoon						
40	0,5 ± 0,02	0,5 ± 0,08	0,4 ± 0,02	1,4 ± 0,10	————	————
80	0,8 ± 0,05	1,3 ± 0,73	1,6 ± 0,55	3,7 ± 0,70	————	————
120	1,9 ± 0,56	1,6 ± 0,38	1,4 ± 0,25	5,0 ± 1,10	————	————
Sum of crops						
40	6,5 ± 0,7	2,5 ± 0,3	3,1 ± 0,2	12,1 ± 0,5	1,4 ± 0,4	13,5 ± 0,5
80	15,4 ± 1,8	5,1 ± 0,6	9,0 ± 1,1	29,5 ± 2,1	2,2 ± 0,5	31,7 ± 2,0
120	13,9 ± 1,6	7,0 ± 1,3	6,9 ± 1,3	27,8 ± 3,3	2,5 ± 0,8	30,3 ± 3,2

Table 2. Utilization by sugar cane of urea- ^{15}N applied at planting. São Martinho Ethanol plant field

Season	Stalks	Dry Leaves	Tips	Above ground Part
	kg/ha			
Planted Cane	18,9 ± 2,1	3,1 ± 0,3	2,7 ± 0,7	24,7 ± 3,1
1st Ratoon	1,3 ± 0,4	0,7 ± 0,2	2,0 ± 0,7	3,9 ± 1,2
2st Ratoon	0,9 ± 0,3	0,6 ± 0,1	1,4 ± 0,6	2,9 ± 0,4
Sum of Crops	21,0 ± 0,2	4,4 ± 0,3	6,1 ± 1,3	31,5 ± 1,4

Table 3. Utilization by sugar cane to urea-¹⁵N applied at planting. Santa Adélia Ethanol plant field

Planted Cane						
N Rates (kg/ha)	Stalks	Dry Leaves	Tips	Above ground Part	Roots	Entire Plant
	kg/ha					
40	6,1 ± 0,8	3,2 ± 0,2	2,2 ± 0,2	11,5 ± 1,0	0,8 ± 0,1	12,3 ± 1,0
80	9,7 ± 1,7	5,9 ± 0,8	3,1 ± 0,6	18,7 ± 2,8	1,3 ± 0,3	20,0 ± 3,0
120	13,5 ± 1,3	6,7 ± 2,1	3,2 ± 0,5	23,4 ± 3,0	1,5 ± 0,3	24,9 ± 3,0
1st Ratoon						
40	1,0 ± 0,16	0,4 ± 0,05	0,6 ± 0,12	2,0 ± 0,31	————	————
80	1,8 ± 0,27	1,1 ± 0,17	1,5 ± 0,41	4,4 ± 0,79	————	————
120	1,8 ± 0,28	1,2 ± 0,57	0,5 ± 0,33	3,5 ± 0,72	————	————
2nd Ratoon						
40	0,5 ± 0,10	0,2 ± 0,01	0,2 ± 0,02	0,8 ± 0,09	————	————
80	0,7 ± 0,25	0,3 ± 0,15	0,3 ± 0,17	1,3 ± 0,53	————	————
120	0,7 ± 0,08	0,4 ± 0,03	0,5 ± 0,09	1,6 ± 0,17	————	————
Sum of Crops						
40	7,5 ± 0,21	3,8 ± 0,05	2,9 ± 0,13	14,3 ± 0,37	0,8 ± 0,1	15,1 ± 0,4
80	12,2 ± 0,12	7,3 ± 0,23	4,9 ± 0,37	24,4 ± 0,58	1,3 ± 0,3	25,7 ± 0,6
120	16,0 ± 0,33	8,3 ± 0,58	4,2 ± 0,38	28,5 ± 0,84	1,5 ± 0,3	30,0 ± 0,8

Conclusion

These results showed that the nitrogen fertilization in a crop season also can be used by the crop in subsequent ratoons, and the amount recovered will depend on the crop management adopted, since the efficiency of nitrogen fertilization in this work, considering the three crop seasons, was low, about 35% of total N applied at planting.

References

- Empresa Brasileira de Pesquisa Agropecuária. Centro Nacional de Pesquisas de Solos (2006) Sistema brasileiro de classificação de solos. 306p. (Embrapa Solos, 2.ed.: Rio de Janeiro).
- Penatti CP, Donzelli JL, Forti JA (1997) Doses de nitrogênio em cana-planta. in: seminário de tecnologia agrônômica, 7., piracicaba, 1997. **anais** piracicaba: centro de tecnologia da copersucar, 1997. p.340-349.
- Orlando Filho J, Rodella AA, Beltrame JA, Lavorenti NA (1999) Doses, fontes e formas de aplicação de nitrogênio em cana-de-açúcar. *Stab - Açúcar, Alcool e Subprodutos* **17**, 39-41.
- Cantarella H, Trivelin PCO, Vitti AC (2007) Nitrogênio e enxofre na cultura da cana-de-açúcar. In: Nitrogênio e enxofre na agricultura brasileira. (Eds T Yamada, SRSE Abdalla, GC Vitti) pp. 355-412. (IPNI Brasil: Piracicaba)
- Espironelo A, Raij BV, Penatti CP, Cantarella H, Morelli JL, Orlando Filho J, Landell MGA, Rossetto R (1996) Cana-de-açúcar. In: Recomendações de adubação e calagem para o estado de são paulo. (Eds BV Raij, H Cantarella, JA Quaggio, AMC Furlani) pp. 237-239. (Fundação IAC: Campinas)
- Vitti AC, Trivelin PCO, Gava GJC, Penatti CP, Bologna IR, Faroni CE, Franco HCJ (2007) Produtividade da cana-de-açúcar relacionada ao nitrogênio residual da adubação e do sistema radicular. *Pesquisa Agropecuária Brasileira* **42**, 249-256.
- Franco HCJ, Bologna IR, Faroni CE, Vitti AC, Trivelin PCO (2007) Acúmulo de macronutrientes em cana-de-açúcar em função da adubação nitrogenada e dos resíduos culturais incorporados ao solo no plantio. *Bragantia* **66**, 521-526.

Effect of Long-Term Nitrogen Fertilization on Main Soil Chemical Properties in Cambisol

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Abstract

Nitrogen fertilization is the most influential in terms of increasing crop production. Mineral nitrogen, in addition to increasing the content of nitrate in soil, leads to changes in soil pH and many other soil properties. Long-term mineral nitrogen addition experiments (over 40-years) can give us valuable information about how those changes occur and point out the trends of the changes. The experiment was set up on a Cambisol 40 years ago with 60, 90 and 120 kg of N per ha. The results show significant increases in N content, humus and soil CEC, while the sum of bases and base saturation decreased.

Introduction

The changes in soil quality are closely related to soil physical, chemical and biological fertility (Zhang *et al.* 2007, Brady and Weil 2002). There is general agreement, that of all the nutrient amendments made to soil, N fertilizer application has had and still has by far the most important effects in terms of increasing crop production. Under intensified agricultural production the soil receives ever more nitrogen (Freny, 2005, Erisman *et al.* 2005;). Fertilizer nitrogen, apart from increasing the content of nitrate in soil that leads to its leaching (Porter *et al.* 1996), results in changes in soil pH and many other soil properties (Brady and Weil, 2002,). Long-term field experiments with N fertilization can give a valuable information about how those changes occur and indicate the trends of the changes.

Materials and Methods

The investigation was conducted on "Mladenovac" experimental station located 55 km from Belgrade in Serbia. This site has received a wide range of different fertilization treatments since 1964. Soil type is *Cambisol*. Mean annual precipitation is about 700 mm and mean annual temperature is 11°C. The mineral N was added as urea and monoammonium phosphate fertilizers in three doses (60-, 90- and 120 kg per ha) for the last 40 years. Soils were sampled from each of three replicates that were designed as 5 x 11 m plots in a randomized complete block experiment, including the control treatment that didn't receive any fertilizer. Soils were sampled from the 0-30 cm soil interval in spring 1998. Five subsamples were taken from each of the replicates and then mixed to make a composite sample for every replicate. Soil pH, content of humus (Tyurin method), total N (Kjeldahl method), available P and K after extraction by the Egner-Riehm method potassium determined on a flame emission photometer, and phosphorus on a spectrophotometer (Enger and Riehm, 1958). Soil Ca, Mg, Fe and Zn were extracted by ammonium acetate, Cu by HCl followed by determination on atomic absorption analyzer SensAA Dual (Wright and Stuczynski, 1996). Soil microelements were analyzed on a composite sample. Determination of CEC was done by the steam distillation method after treatment of the samples with ammonium acetate (Sumner and Miller, 1996). Statistical analyses were performed by SPSS 16 software program. The effects of treatments on all the variables were tested using an ANOVA method. Statistical differences were determined using t-test for Fishers LSD. The significance of their correlations was analyzed by Pearson correlation matrix (SPSS Inc., 2007).

Results

The studied soil in the control treatment is classified as Eutric Cambisol with medium humus content. The content of available P is medium, and K is high. Nitrogen fertilizer primarily affected the soil pH resulting in an increase in acidity. The clear trend of decreasing soil pH was observed with increasing the rate of applied N-fertilizer where the high statistical significance was observed between the control and the highest rate of N-fertilizer. The content of N also was constantly increasing corresponding to the applied fertilizer rate with statistical significance between all four treatments. Soil organic matter did not show a changing trend, however, there was a significant increase in the content of humus between control and 60 kg and 120 kg N per ha. The content of P increased for 60 and 90 kg N per ha versus control, while in the 120 kg N per ha it somewhat decreased. The content of K also increased compared to the control although the increase was not regular. There was a clear significant increase of soil CEC, while sum of bases decreased parallel with applied N. Magnesium and Ca showed a clear trend of decreasing parallel to the applied N. Changes in the

contents of available Fe and Zn were contradictory compared to other microelements showing increases with addition of N-fertilizer.

Table 17. Average contents of main soil properties in long-term N-fertilization experiment in Cambisol, Serbia

kg N per ha	pH	humus	total N	P	K	Ca	Mg	sum of base	CEC	sum of base	Zn	Fe	Cu
		%	mg/100g				Cmol/100g			%	mg/kg		
0	5.79a	2.17a	0.10a	4.83a	19.38a	384	101	12.7a	20.7a	61a	0.55	25.40	8.60
60	5.37b	2.45b	0.13b	11.77b	28.21b	287	71	11.6b	23.4b	50b	1.04	26.00	7.80
90	5.33b	2.27c	0.16c	11.82b	24.79b	304	63	10.7c	23.0b	47c	1.03	26.33	7.43
120	5.00c	2.36d	0.19d	11.48b	26.50b	311	57	9.6d	24.1c	40d	1.04	27.07	7.00
LSD	*	*	*	*	*	ND	ND	*	*	*	ND	ND	ND

*significant at 0.05 level

Discussion

Long-term application of N containing fertilizers (such as MAP) with acidifying effects, results in acidification of soil, thus lowering soil pH (Belay *et al.* 2002). Upon oxidation, NH_4^+ can release H^+ ions – a potential source of soil acidity (Magdoff *et al.* 1997). Soil pH is one of the main factors affecting solubility of trace elements and their phyto-availability (e.g. Kopec and Przetaczek-Kaczmarczyk 2006).

Permanent fertilization with N can lead to its leaching, where firstly the processes of nitrification build up nitrate ions, which are weakly associated to soil adsorptive complex (Mengel and Kirkby, 2001). On the other hand, processes of microorganism metabolism also affect the mineral N and microorganisms are included into the soil humus that is usually reflected in an increased content of SOM. However, in our study the expected increase in soil humus did not show a clear dependence on the amount of applied N. This can be explained partially by the changes in the composition of SOM, where addition of mineral N intensified immobilization of mineral N by microorganisms (Ilyaletdinov, 1988; Karborzova-Salnikov, 2004), and by adsorption of ammonium by soil CEC and by processes of weak fixation within clay minerals (Mengel and Kirkby, 2001). Such processes can result in gradual accumulation of total N.

Table 18. Pearson Correlation Coefficients of soil main properties as affected by long-term application of N-fertilizer in a Cambisol, Serbia

	pH	humus	TN	P	K	sum of bases	CEC	sum of base
pH	1							
Humus	-.141	1						
Total N	-.703**	.165	1					
P	-.545**	.167	.452**	1				
K	.213	.262	-.324*	-.579**	1			
bases	.749**	-.123	-.663**	-.615**	.402*	1		
CEC	-.552**	.204	.435**	.243	.088	-.003	1	
Sum of bases	.927**	-.216	-.773**	-.672**	.316*	.881**	-.471**	1

** Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

Increases in the content of available K and P in the fertilized treatments are expected. However, addition of the highest rates of N resulted in a somewhat decreased content of P, which is probably induced by reduced solubility of P-compounds due to increased soil acidity (Marsh *et al.* 1987). Decreased content of exchangeable Ca compared to the control clearly indicates an imbalance between its input and output. The reason for this is the leaching due to soil acidification and processes of nitrification that particularly apply to soils with a pH <7. This is also confirmed by the decreasing trend in the content of Mg in the studied surface soil, compared to the control (Mengel and Kirkby, 2001).

Decreases in soil pH, followed by leaching of soil bases are also clearly seen in the constant decrease of basic cations on the soil CEC, whilst the increased content of humus resulted in an increased value of soil CEC (Yan *et al.* 2007). The significant decrease of basic cations on the soil CEC resulted in the changes of main soil properties resulting in a change in soil classification: the studied Eutric Cambisol has become a Dystric Cambisol. Changes in the content of Zn and Fe are closely connected to the decrease of soil pH, e.g. due to acidification of the medium Zn and Fe are activated and transformed into mobile forms that determine their increased content for the fertilized treatments (Mengel and Kirkby 2001). On the other hand, strong bonds of insoluble Cu with soil particles, and the higher concentration of Cu than of Zn in soil solution resulted in leaching due to soil acidification (Mc Bride 1989; Mengel and Kirkby 2001).

References

- Belay A, Claassens AS, Wehner FC (2002) Effects of direct nitrogen and potassium and residual phosphorus fertilizers on soil chemical properties, microbiological components and maize yield under long-term crop rotation. *Biol. Fertil. Soils* **35**, 420-427.
- Brady AC, Weil RR (2002) The Nature and Properties of Soils. 13th Edn. Prentice Hall, New jersey, USA
- Enger H, Riehm H (1958) Die Ammoniumlaktatessigsäure-Methode zur Bestimmung der leichtlöslichen Phosphorsäure in Karbonathaltigen Böden (In German). *Agrochimica* III(1):49-65.
- Erisman JW, Domburg N, de Vries W (2005) The Dutch N-cascade in the European perspective // Science in China. *Series C. Life Sciences* **48**, 827-842.
- Freney JR (2005) Options for reducing the negative effects of nitrogen in agriculture. Science in China. *Series C. Life Sciences*. **48**, 861-870.
- Ilyaletdinov A (1988) Microbiological conversion of nitrogen compounds in the soil, 2nd ed. *Nauka*, Moscow.
- Karbozova-Salnikov E (2004) Soil organic matter status of Chernozem soil in North Kazakhstan: effects of summer fallow. *Soil Soil Biochem.* **36**, 1373-1381.
- Kopec M, Przetaczek-Kaczmarczyk M (2006) Changes of soil abundance in microelements in long-term fertilization experiment (Czarny Potok) (In Poland with English abstract). *Polish J. Soil Sci.* **XXXIX/1**, 91-96.
- Magdoff F, Lanyon L, Liebhardt B (1997) Nutrient cycling, transformation and flows: Implications for a more sustainable agriculture. *Adv. Agron* **60**, 1-73.
- Marsh KB, Tillman RW, Syers JK (1987) Charge relationship of sulfate sorption by soil. *Soil Sci. Soc. Am. J.* **51**, 318-323.
- McBride MB (1989) Reactions controlling heavy metal solubility in soil. *Adv. Soil Sci. Soc. Am. J.* **10**, 1-56.
- Mengel K, Kirkby EA (2001) Principles of plant nutrition. 5th ed., Kluwer Academic Publishers, Netherlands.
- Porter LK, Follet RF, Halvorson AD (1996) Fertilizer nitrogen recovery in a no-till wheat-sorghum fallow-wheat sequence. *Agron.J.* **88**, 750-757.
- SPSS Inc. (2007) SYSTAT version 16, Statistics, Chicago, IL.
- Sumner ME, Miller WP (1996) Cation exchange capacity and exchange coefficients. In *Methods of Soil Analysis. Part 3.* (Ed DL Sparks) pp. 1201-1229. (SSSA, Madison).
- Zhang XY, Sui XY, Zhang XD, Meng K, Herbert SJ (2007) Spatial variability of nutrient properties in black soil of northeast China. *Pedosphere* **17**, 19-29
- Wright RJ, Stuczynski T (1996) Atomic Absorption and Flame Emission Spectrometry. In 'Methods of Soil Analysis. Part 3'. (Ed DL Sparks.) pp.65-90. (SSSA, Madison, WI).
- Yan Jun-Hua, Guo-Yi Zhou, De-Qiang Zhang, Guo-Wei Chu (2007) Changes of Soil Water, Organic Matter, and Exchangeable Cations Along a Forest Successional Gradient in Southern China. *Pedosphere* **17**(3), 397-405.

Nutrient management for sugar beet (*Beta vulgaris* L.) on K-fixing soils

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Abstract

Alluvial soils with illite and vermiculite clay minerals are highly potassium (K)-fixing. Such soils have been reported to require a huge amount of K fertilization for optimum plant growth. For halophytic plants such as sugar beet, sodium (Na) can be an alternative to K under such conditions. This study was conducted to investigate the possible substitution of K by Na fertilization with reference to K-fixing soils. Three soils i.e. Kleinlinden (sub-soil), Giessen (alluvial), and Trebur (alluvial) differing in K-fixing capacity, were selected and sugar beet plants were grown in Ahr pots with 15 kg soil pot⁻¹. Plants were grown till beet maturity and beets were analyzed for sucrose concentration and other quality parameters such as α -amino nitrogen to calculate white sugar yield with the New Brunswick formula. The results showed that growth and quality of sugar beet were not affected by Na application and ultimately there was no decrease in white sugar yield. The soils with more K-fixing capacity were more effective for K substitution by Na. It is concluded that Na can substitute K in sugar beet nutrition to a high degree and soils with high K-fixing capacity have more potential for this substitution.

Key Words

potassium, sodium nutrition, K-fixing soil, *Beta vulgaris* L.

Introduction

Sometimes plant growth does not respond to generally recommended K fertilization in the soils with expandable clay minerals such as vermiculite. Doll and Lucas (1973) reported for Michigan State that in such sandy clay loam soils, about 92% of the applied K fertilizer had been fixed. A response of K application to a tomato crop was obtained at 1600 kg K/ha. These soils are rich in illite and vermiculite, weathered from mica and are able to fix a huge amount of K. In such soils a major portion of applied K is fixed and becomes unavailable to plants immediately. Similar results have been achieved in other parts of the USA (Mengel and Kirkby 2001).

Potassium is involved in three important functions i.e. enzyme activation, charge balance and osmoregulation in plants (Mengel 2007). Plants need a smaller amount of K for specific functions that occur in the cytoplasm and a major portion (90 %) of K is localized in vacuoles where it acts as an osmoticum (Subbarao *et al.* 2000). Maintenance of osmotic equilibrium in vacuole and cytoplasm, a non-specific function of K, can be replaced by other cations such as the Na ion (Subbarao *et al.* 1999).

In sugar beet, application of Na (equivalent to K fertilizer) prevented the occurrence of K deficiency symptoms (Wakeel *et al.* 2009). The possibility of substitution of K by Na in physiological processes is not only of academic interest but is also of practical importance in relation to fertilizer application. It seems essential to examine the possibilities of the practical application of these findings. In highly K-fixing soils an enormous amount of K fertilizer is needed to stimulate plant growth and yield formation. Application of a huge fertilizer amount is very expensive and hardly practicable. In this study we investigated the possibility of K substitution by Na with reference to K-fixing soils. This may lead us to consider Na as an alternative to K fertilization and the development of an improved fertilizer strategy for sugar beet on K-fixing soils.

Methods

A soil experiment was carried out in Ahr pots at the experimental station of the Institute of Plant Nutrition, Giessen. Three soils i.e. Kleinlinden, Giessen and Trebur, differing in K-fixing capacities (Tab. 1) were filled into Ahr pots at the rate of 15 kg each. A lower concentration of exchangeable K was achieved by dilution with sand at ratios of 1:1 (Kleinlinden and Giessen) and 1:10 (Trebur). The soils were mixed with MgCO₃, Ca(H₂PO₄)₂ + CaSO₄ (superphosphate), NH₄NO₃ and H₃BO₃ at rates of 0.133, 1.910, 0.380 and 0.003 g/kg of soil, respectively. There were three treatments, i.e. (1) no K or Na application, (2) K application according to the K-fixing capacity of the soil, and (3) Na application equivalent to a regular K fertilization (145 kg Na/ha), with four replications for each. Plants were harvested at beet maturity about four months after sowing. Then

the plants were washed in distilled water and were separated into young leaves, old leaves, and beet for fresh weight measurements. Oven-dried (80°C) plant materials were weighed and ground to pass a 1.0 mm sieve. Shoot and beet samples were analyzed for K, Na, Ca and Mg. Beet was analyzed for sucrose and α -amino N.

Another experiment was conducted in big containers (170 kg soil each) using Kleinlinden soil. Three treatments, i.e. control without application of Na and K, K according to regular K fertilization (415 kg K/ha) and Na equivalent to K fertilization were applied. Harvesting was done similarly to the previous experiment.

Table 1: Physicochemical characteristics of the soils used for the experiments.

Soils	Soil type	pH (0.01M CaCl ₂)	Clay (g/kg)	Silt (g/kg)	Sand (g/kg)	N _{total} (%)	Exch. Mg (mg/kg)	CAL*-K (mg/kg)	K-fixing capacity of soil (mg K/kg)
Kleinlinden	Sub-soil	5.8	207	338	455	0.042	245	49.1	488
Giessen	Alluvial	5.2	303	631	47	0.241	296	26.9	526
Trebur	Alluvial	7.4	446	436	112	0.432	229	254.0	617

*Calcium acetate lactate extractable

Results

In a preliminary experiment, K and Na application resulted in an increase of leaf and white sugar yield of sugar beet compared to the control treatment and on each soil the highest leaf and white sugar yields were obtained in the treatment with K, since the K fertilization was equivalent to the K-fixing capacity of the soil. However, Kleinlinden soil for showed significantly higher yields for K treatment as compared to the Na treatment because of better K response due to low K-fixing capacity (Figure 1). In the container experiment, leaf fresh and leaf dry weights were not affected by Na and K treatments as compared to those of the control treatment, however beet fresh and dry weights in the K and Na treatments were significantly higher than those in the control treatment but not different to each other (data not shown) and similar results were found for white sugar yield (Figure 1).

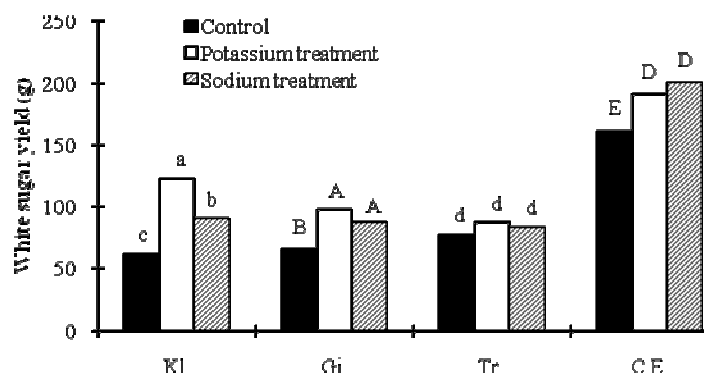


Figure 1. Effect of K substitution by Na on white sugar yield of sugar beets harvested at maturity in three soils (Kl. = Kleinlinden, Gi. = Giessen, Tr. = Trebur and C.E. = container experiment). In Ahr pot experiment K fertilizer was applied according to the K-fixing capacity of soil i.e. 950, 1026, and 240 kg K/ha in Kl., Gi., and Tr. soils, respectively. In the container experiment K was applied according to regular K fertilization (415 kg K/ha). Sodium was applied equivalent to regular K fertilization. Means followed by the same letter for the same soil are not significantly different according to LSD test at 5% level of probability.

Sodium treatment reduced the uptake of K without disturbing the growth of the plants. Ca and Mg concentrations decreased in the leaves when K was substituted by Na but this response was not consistent in all the soils. Interestingly, Na + K concentration in beet was decreased when K was substituted by Na, which definitely improved the quality of beet by decreasing the molassegenic effect. The concentrations of sucrose and α - amino N were not affected by K substitution by Na.

Discussion

Many essential metabolic processes can function equally well with a number of different but chemically similar elements. According to Subbarao *et al.* (2003), it is possible for similar elements such as Na and K to replace each other completely in certain non-specific metabolic functions. Our experiments with sugar beet showed peculiar effects of Na application on plant growth and Na was able to eliminate the K deficiency symptoms of sugar beet leaves. Surprisingly, despite a very low K ion concentration K deficiency symptoms

were not observed in the Na treatment. Subbarao *et al.* (2003) concluded that Na can replace K for vacuolar functions for which 95% of total acquired K is required. In our experiments, we applied a lower amount of Na, which may have taken over the osmotic functions of K in vacuoles without disturbing K concentrations in the cytosol (Jeschke 1977). Therefore, the plant growth was maintained. Apparent growth stimulation by Na in the plants of the family *Chenopodiaceae* was observed (Jafarzadeh and Aliasgharzad 2007). Similarly, Nunes *et al.* (1983) found that growth of halophytic plants was stimulated by Na, mainly through an effect on cell expansion.

The Ahr pot experiment with soil Kleinlinden showed decreased plant growth and white sugar yield when K was substituted by Na (Figure 1). Elevated K concentration of the leaves of plants grown in Kleinlinden soil revealed that the higher growth response was due to better K availability in the K treatment as compared to the other soils due to low K-fixing capacity of the Kleinlinden soil, which was about 40 mg K (kg soil)⁻¹ less than of Giessen soil used in the same experiment (Tab. 1). In the container experiment, Na and K treatment did not show a significant difference because K applied was relatively less (equal to regular K fertilization). Giessen soil showed no significant difference in plant growth and white sugar yield when K was substituted by Na. In Trebur soil, K and Na both did not show a significant effect on leaf growth and white sugar yield in comparison to the control. Similar results have been found in a field study conducted at Trebur with similar soil (unpublished). Such types of soil are able to release K from the huge amount of total K present in the soil (Schubert *et al.* 1989) when its concentration in soil solution decreases (Figure 2). The total amount of K in this soil was 16 g K (kg soil)⁻¹.

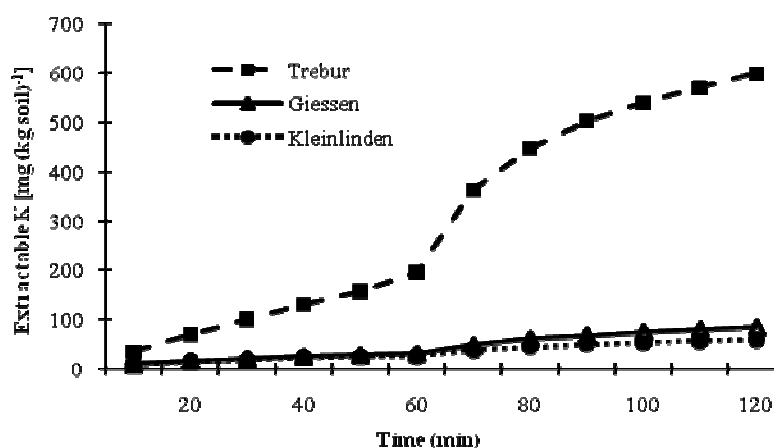


Figure 2. Cumulative curve of extractable K in three different soils determined with electro-ultra filtration (EUF). Soil extract was taken every 5 min. Potassium released during the first 60 min at 200V/20°C is considered as easily available for plants and K release in following 60 min at 400V/80°C is known to be slowly available for plants.

Higher concentrations of α -amino N and K + Na decrease the quality of beet because their presence in the beet interferes with the crystallization process, which causes a great proportion of the sugar to be recovered as molasses with a reduction in refined sugar (Hilde *et al.* 1983; Carter, 1985). Application of Na fertilizer could decrease the quality of the sugar beet if its major accumulation occurred in the beets. Wang *et al.* (2007) found that most of the halophytic plants accumulated a huge amount of Na in their shoots. For *Suaeda maritima*, a halophytic plant growing in 150 mM NaCl, he found that 95% of the total Na was accumulated in plant shoots. We also found that a major portion (90% of total plant Na content) was accumulated in sugar beet shoots.

Haneklaus *et al.* (1998) concluded that the sugar beet root was negatively affected by Na fertilization due to an increase in Na content in the beet. Our studies also showed a slightly significant higher Na concentration in the beet in Na-fertilized plants as compared to K-fertilized plants, but K concentrations in the beets of the Na treatment were much lower than those in the K treatment. Farley and Draycott (1974) concluded that Na and K have similar molassegenic effects on sugar extraction. We calculated that the K + Na concentration was significantly decreased in the Na treatment as compared to that in the K treatment improving the beet quality in this regard. Sucrose and α -amino N concentrations in the beet were similar in the K and Na treatment.

It is concluded that substitution of K by Na stimulates plant growth without affecting beet yield and quality. Soils with higher K-fixing capacity have more potential for this substitution and application of a huge amount of expensive K fertilizer can be replaced with small amounts of cheaper Na fertilizer.

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References

- Carter JN (1986) Potassium and sodium uptake effects on sucrose concentration and quality of sugar beet roots. *Journal of American Society of Sugar Beet Technologist* **23**, 183-202.
- Doll EC, Lucas RE (1973) Testing soils for potassium, calcium and magnesium. In 'Soil testing and plant analysis' (Eds. Walsh LM, Beaton JD) 3rd ed., pp 133-152. (SSSA Book Ser 3 SSSA Madison, WI)
- Farley RF, Draycott AP (1974). Growth and yield of sugar beet in relation to potassium and sodium supply. *Journal of the Science of Food and Agriculture* **26**, 385 – 392.
- Hajibagher MA, Hall JL, Flowers TJ (1984). Stereological analysis of leaf cells of the halophyte *Suaeda maritima* L. Dum. *Journal of Experimental Botany* **35**, 1547 - 1557.
- Haneklaus S, Knudsen L, Schnug E (1998). Relationship between potassium and sodium in sugar beet. *Communications Soil Science and Plant Analysis* **29**, 1793 – 1798.
- Hilde DJ, Bass S, Levos RW, Ellingson RL (1983). Grower practices system promotes beet quality improvement in red river valley. *Journal of American Society of Sugar Beet Technologist* **22**, 73 – 88.
- Jafarzadeh AA, Aliasgharzad N (2007). Salinity and salt composition effects on seed germination and root length of four sugar beet cultivars. *Biologia Bratislava* **62**, 562 - 564.
- Jeschke WD (1977). K⁺ - Na⁺ exchange and selectivity in barley root cells: Effects of Na⁺ on Na⁺ fluxes. *Journal of Experimental Botany* **28**, 1289 - 1305.
- Mengel K (2007). Potassium. In 'Handbook of Plant Nutrition' (Eds. Barker AV, Pilbeam DJ) 1st ed. pp 91-120. (Taylor & Francis NY)
- Mengel K, Kirkby EA (2001). Principles of Plant Nutrition. (Kluwer Acad. Publishers, Dordrecht, Boston, London)
- Nunes MA, Correia MM, Lucas MD (1983). NaCl-stimulated proton efflux and cell expansion in sugar beet leaf discs. *Planta* **158**, 103 - 107.
- Rengel Z (1992): The role of calcium in salt toxicity. *Plant Cell and Environment* **15**, 625 – 632.
- Schubert S, Paul R, Uhlenbecker K (1989). Charakterisierung des nachlieferbaren Kaliums aus der nichtaustauschbaren Fraktion von acht Böden mittels einer Austauschermethode und EUF. *VDLUFA-Schriftenreihe* **30**, 329 -334.
- Subbarao G V, Wheeler RM, Stutte GW (2000). Feasibilities of substituting sodium for potassium in crop plants for advanced life support system. *Life Support and Biosphere Science* **7**, 225 - 232.
- Subbarao GV, ItoO, Berry WL, Wheeler RM (2003). Sodium - A functional plant nutrient. *Critical Review in Plant Science* **22**, 391 - 416.
- Subbarao GV, R.M. Wheeler RM, Stutte GW, Levine LH (1999). How far can sodium substitute for potassium in red beet? *Journal of Plant Nutrition* **22**; 1745–176
- Wakeel A, Abd-El-Motagally F, Steffens D, Schubert S (2009). Sodium-induced calcium deficiency in sugar beet during substitution of potassium by sodium. *Journal of Plant Nutrition and Soil Science* **172**, 254 - 260.
- Wang SM, Zhang JL, Flowers TJ (2007). Low-affinity Na⁺ uptake in the halophyte *Suaeda maritima*. *Plant Physiology* **145**, 559 - 571.

Where in the world is the potash that we need?

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Abstract

Since January 2007, the price of muriate of potash (KCl) has increased 4 times, reaching US\$1000/T K₂O equivalent for some contracts during 2008. Independently, estimates of nutrient balance suggest that global production needs to double to replace observed agricultural offtake of K. In these circumstances, it is appropriate to consider the use of crushed silicate rocks as a cost effective alternative way of replenishing soil K stocks. Such rocks are widely distributed, and could play a significant role in maintaining soil fertility for the poorest farmers.

Key Words

Potash, feldspar, crushed rock, fertiliser.

Introduction

Potassium (K, or potash, K₂O), like nitrogen (N) and phosphorus (P), is vital for the growth of healthy plants and crops. Without it, plants are unable to make good use of other fertilisers, especially N. Both P and K fertilisers are exclusively derived from geological (rock) sources, and almost all N is obtained from natural gas or atmospheric sources. N, P and K fertilisers are produced by a global industry that derives raw materials from a limited number of locations, and the resulting fertiliser products are traded globally as bulk products. The price of fertilisers has changed dramatically since the beginning of 2007 (Figure 1). As examples, the prices of diammonium phosphate (DAP) and urea tend to follow changes in the oil price, partly because ten times as much energy is used in the manufacture of nitrogen fertilisers compared with potash (Lægriid *et al.* 1999). N and P prices decreased at the end of 2008, as part of the global recession, and are now at or below the prices for the start of 2007. In contrast, the price of K, as muriate of potash (MOP), has stayed high. At its peak in 2008, MOP reached an index price of US\$800 per tonne, and in some markets (e.g. Brazil) prices of US\$1000 per tonne were achieved. The MOP price has fallen back to about US\$650 per tonne, almost 4 times higher than in January 2007, and over 5 times higher than the price in 2000 (US\$120/tonne).

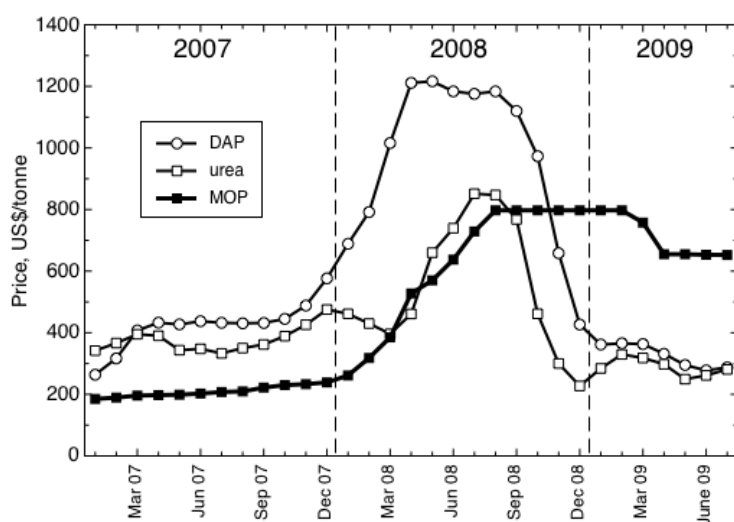


Figure 1. Variation in prices of phosphorus (diammonium phosphate; DAP), nitrogen (urea) and potassium (muriate of potash; MOP) fertilisers since 2007. Calculated using data from www.icis.com).

Potash demand

Global potash production in 2007 was around 30 million tonnes/year as K₂O (USGS, 2008), dominated by production from Canada (11 million tonnes/year), Russia (6.3 million tonnes/year) and Belarus (5.4 million tonnes/year).

According to the Food and Agriculture Organisation of the United Nations (FAO 2008), supply of potash is expected to meet demand, which will grow at about 2.4% per year. However, this approach does not necessarily fully consider the underlying need for potash in developing countries. Taking Africa as an example, the FAO reports that on a continental scale 47 out of 57 African countries do not consume fertiliser products in any significant way, and that the entire continent consumes only 485,000 tonnes of potash annually. This again is expected to grow at around 2% annually, and is all imported. Thus about 1.5% of global potash production is currently being used to support about 15% of the world's population. Under these circumstances, demand must surely exceed supply, although it may not exceed ability to purchase.

The need for fertiliser inputs can be estimated using an alternative approach, in which a nutrient budget is determined that balances nutrients removed by cropping against inputs from fertilisers, crop residues and manures or composts (Sheldrick *et al.* 2002). Using this approach, Sheldrick *et al.* (2002) showed that, compared with N and P, K is the nutrient that is most seriously in deficit. Globally, there is an annual deficit of 20 kg K per hectare. In order to balance nutrient offtakes, Africa needs to find inputs equivalent to 4.1 million tonnes of K per year, or around 5 million tonnes of K₂O, or ten times the continent's current consumption (Sheldrick and Lingard 2004). At current prices, this would cost several billion dollars. At a global scale, Sheldrick *et al.* (2002) analysis suggests that worldwide potash consumption needs to be doubled to maintain soil nutrient balances, requiring an additional 60 million tonnes of KCl ore to be mined. This deficit is currently being removed from the soils by current agricultural practices, representing nutrient mining on an evidently unsustainable scale.

Alternative potash sources

Given that conventional potash sources might be unable to respond to demand, it is appropriate to consider alternatives. Over the years (e.g. Harley and Gilkes 2000), a number of studies have investigated the possible use of potassium silicate minerals, such as feldspars or their host rocks, especially granites. These materials are widely distributed, and are readily available. As parent soil-forming materials, they undoubtedly provided much of the original K content of a soil. However, critical reviews (Harley and Gilkes 2000; Manning 2009) show that it is difficult to identify reports where there is a sound statistical basis for promoting their use, although these materials are traded commercially for some agricultural sectors. In some cases (e.g. Sanz Scovino and Rowell 1988), the use of feldspar gives a measurable yield response, but the low cost of conventional K at that time led the authors to conclude that feldspar is not a viable alternative. Table 1 lists the most common potassium silicate minerals, giving not only their K contents but (where available) their dissolution rates relative to that determined for potassium feldspar (orthoclase; Blum and Stillings 1995), which has a value for the dissolution rate, log k^+ , of -10.2. It is the dissolution rate, rather than the absolute K content, that determines whether or not K is available to the soil system within a given period of time appropriate for crop growth.

Table 1. Summary of the composition of the major potassium silicate minerals, and their relative dissolution rates (Manning 2009).

Mineral	Mineral family	Formula	Weight % K	Weight % K ₂ O	Relative dissolution rate
Potassium feldspar	Feldspar	KAlSi ₃ O ₈	14.0	16.9	1-2
Leucite	Feldspathoid	KAlSi ₂ O ₆	17.9	21.6	nd ¹
Nepheline	Feldspathoid	(Na,K)AlSiO ₄	13.0	15.7	40-100
Kalsilite	Feldspathoid	KAlSiO ₄	24.7	29.8	nd
Muscovite	Mica	KAl ₃ Si ₃ O ₁₀ (OH) ₂	9.0	10.9	n/a ²
Biotite	Mica	K ₂ Fe ₆ Si ₆ Al ₂ O ₂₀ (OH) ₄	7.6	9.2	n/a
Phlogopite	Mica	K ₂ Mg ₆ Si ₆ Al ₂ O ₂₀ (OH) ₄	9.4	11.3	n/a

¹not determined

²not applicable

Referring to Table 1, it can be seen that there are limited data for mineral dissolution rates, and it is not really appropriate to consider dissolution rates for the micas given the importance of cation exchange in controlling their ability to release K. Importantly, however, the dissolution rate of nepheline, a feldspathoid, is two orders of magnitude greater than that of orthoclase feldspar (Blum and Stillings 1995; Tole *et al.* 1986). In the absence of additional information, it can be assumed that the other feldspathoids have similar dissolution rates to nepheline given similarities in their crystal structure. It must be recognised that leucite within

volcanic rocks and shallow intrusives is very commonly hydrothermally altered to zeolites that include potassic species such as phillipsite (e.g. Weisenberger and Spurgin 2009), and that these may provide a source of K with a high cation exchange capacity.

Crop trials with potassium silicate rocks

The use of potassium silicate rocks lies within the domain of the ‘remineralise the Earth’ movement, and has largely attracted support from the alternative agricultural sector. In theory, there are sound mineralogical reasons for this approach to succeed, and there are many satisfied users of such rocks. However, the value of this practice has yet to be demonstrated widely in rigorous scientific trials. Although the use of feldspars and feldspathic rocks has tended to give disappointing results (Manning 2009), experiments carried out with nepheline-bearing rocks have been more positive (Bakken *et al.* 1997; 2000). In pot trials using ryegrass (Bakken *et al.* 1997) and field trials using timothy and meadow fescue (both grasses; Bakken *et al.* 2000), increased dry yields were reported with application of nepheline-bearing rock powders. In field experiments lasting 3 years, application of nepheline bearing rock powders gave similar yields to the equivalent initial application of muriate of potash (Bakken *et al.* 2000). These results are entirely consistent with the observed differences in dissolution rate.

Implications for fertiliser supply

Leonardos *et al.* (1987) are critical of conventional fertiliser practice: “Unfortunately, the standard concept and technology of soil fertilizer is behind that of the superphosphate concept developed by J. B. Lawes in England, 150 years ago. Had this technology been originally developed for the deep leached laterite soils of the tropics instead for (sic) the glacial and rock-debris-rich soils of the northern hemisphere our present fertilizers might have been quite different.” For many poor farmers raising crops on oxisols, the use of crushed rock, including crushed granite, might be the only option that is available to them (Theodoro and Leonardos 2006). In terms of economics, the per unit cost of potash derived from silicate rock sources is now less than the price of conventional muriate of potash, so economic conditions are far less of an obstacle than they once were. The cost of crushing and milling a silicate rock to produce a fertiliser product can be considered against the price of conventional K. For example, using 2007 prices, a feldspar-based product at 16% K₂O would have to be produced at US\$50/tonne or less to compete with MOP, with correspondingly lower target production prices for lower grades. With the price rises that occurred in 2008 and 2009, a feldspar-based product could have a production cost per unit of US\$150/tonne, and still be cheaper per unit of K than muriate of potash. Rocks with 8% and 4% K₂O, in 2009, need production costs of 90 and 45US\$/tonne to have a cost directly comparable to muriate of potash. Although transport costs will be greater (the K content of crushed silicate rocks being less than high grade fertiliser products), the manufacturing costs, for local use, are feasible.

Conclusion

Given the current very high price for K, and the need to maintain soil K stocks and to compensate for extensive nutrient mining especially in deeply weathered soils, potassium-bearing silicate minerals and their host rocks are potentially able to act as an alternative where the cost of conventional K sources prevents their use. On the basis of dissolution rate, it is preferred to use rocks that contain feldspathoids, such as nepheline and leucite. Such rocks are rare, but widely distributed, and may be attractive within an overall strategy to optimise global use of scarce K resources.

References

- Bakken AK, Gautneb H, Myhr K (1997) The potential of crushed rocks and mine tailings as slow-releasing K fertilizers assessed by intensive cropping with Italian ryegrass in different soil types. *Nutrient Cycling in Agroecosystems* **47**, 41-48.
- Bakken AK, Gautneb H, Sveistrup T, Myhr K (2000) Crushed rocks and mine tailings applied as K fertilizers on grassland. *Nutrient Cycling in Agroecosystems* **56**, 53-57.
- Blum AE, Stillings LL (1995) Feldspar dissolution kinetics. In ‘Chemical weathering rates of silicate minerals’ (Eds AFWhite, SL Brantley). *Reviews in Mineralogy* **31**, 291-351.
- FAO (2008) ‘Current world fertilizer trends and outlook to 2011-12’. (FAO: Rome).
www.fao.org/newsroom/en/news/2008/1000792/index.html
- Harley AD, Gilkes RJ (2000) Factors influencing the release of plant nutrients from silicate rock powders: a geochemical overview. *Nutrient Cycling in Agroecosystems* **56**, 11-36.

- Lægrið M, Bøckman OC, Kaarstad O (1999) 'Agriculture, Fertilizers and the Environment'. (CABI Publishing: Wallingford).
- Leonardos OH, Fyfe WS, Kronberg BI (1987) The use of ground rocks in laterite systems – an improvement to the use of conventional soluble fertilizers. *Chemical Geology* **60**, 361-370.
- Manning DAC (2009) Mineral sources of potassium for plant nutrition: a review. *Agronomy for Sustainable Development*, in press (DOI: 10.1051/agro/2009023).
- Sanz Scovino JI, Rowell DL (1988) The use of feldspars as potassium fertilizers in the savannah of Columbia. *Fertilizer Research* **17**, 71-83.
- Sheldrick WF, Lingard J (2004) The use of nutrient audits to determine nutrient balances in Africa. *Food Policy* **29**, 61-98.
- Sheldrick WF, Syers JK, Lingard J (2002) A conceptual model for conducting nutrient audits at national, regional and global scales. *Nutrient Cycling in Agroecosystems* **62**, 61-67.
- Theodoro SH, Leonardos OH (2006) The use of rocks to improve family agriculture in Brazil. *Anais da Academia Brasileira de Ciencias* **78**, 721 – 730.
- Tole MP, Lasaga AC, Pantano C, White WB (1986) The kinetics of dissolution of nepheline ($\text{NaAlSi}_3\text{O}_8$). *Geochimica et Cosmochimica Acta* **50**, 379-392.
- USGS (2008) 'Mineral Commodity Summary 2007: Potash'. (United States Geological Survey: Reston, VA).
- Weisenberger T, Spurgin S (2009) Zeolites in alkaline rocks of the Kaiserstuhl volcanic complex, SW Germany – new microprobe investigation and the relationship of zeolite mineralogy to the host rock. *Geologica Belgica* **12**, 75-91.

Best Management Practices in South Florida: A Success Story

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Abstract

A mandatory Best Management Practices (BMP) program was implemented on Everglades Agricultural Area (EAA) farms in 1995 as required by the Everglades Forever Act to reduce phosphorus (P) loads from drainage waters that enter the Everglades ecosystem. All farms in the EAA basin implement mandatory BMPs. Our objective was to determine long-term P load trends of the basin as well as ten individual farms after implementing BMPs for 7 to 10 yr. Mann-Kendall trend analysis was used to determine the degree of change in water quality trends. Decreasing trends in P loads were observed in the outflow of the basin and two of its sub basins, the S5A and S8. A decreasing trend in P load was observed on sugarcane farms, while mixed crop farms showed either decreasing or insignificant trends. The insignificant trends are likely related to management practices of mixed crop systems. The EAA Basin P load reductions have consistently exceeded the 25% reduction required by law, indicating the success of the program. Differences in P load reduction exist between farms and sub-basins due to differences in cropping and management systems, and environmental factors.

Key Words

Best Management Practices (BMP), phosphorus (P), Everglades agricultural area (EAA), South Florida, Everglades Forever Act (EFA).

Introduction

The Everglades in south Florida is the largest contiguous body of organic soils in the continental United States (Stephens 1956) originally occupying approximately 778,000 ha (Jones 1942). A portion of the northern Everglades was drained at the beginning of the 20th century for agricultural and urban purposes, becoming what is known today as the Everglades Agricultural Area (EAA). The EAA basin is located south and east of Lake Okeechobee and north and west of Water Conservations Areas (WCA) in Florida, U.S. (Figure 1). The EAA comprises an area of approximately 283,300 ha and is planted predominantly to sugarcane (*Saccharum spp.*) with the remaining arable land planted to winter vegetables, sod and rice (*Oryza sativa* L.). The EAA basin has four sub-basins (S5A, S2/S6, S2/S7, and S3/S8). The soils of the EAA, classified as organic (soil order: Histosol), were formed under anaerobic conditions (Snyder and Davidson 1994). Drainage of organic soils has caused the loss of soil through decomposition leading to soil subsidence and variable soil depths. Soils are deepest in the S5A sub-basin and shallowest in the S3/S8 sub-basin.

To farm successfully, growers in the EAA actively drain their fields via an extensive array of canals, ditches, and large volume pumps. Excess water is pumped off farms into South Florida Water Management District (SFWMD) conveyance canals, from which it is pumped to Stormwater Treatment Areas (STA). After treatment, water is sent southward to the WCAs and the Everglades National Park (ENP). Concerns about the quality of drainage water leaving the basin and entering the ENP prompted the Florida legislature to adopt the Everglades Regulatory program, part of the Everglades Forever Act (EFA). The main objective of the program is to reduce P loads from the EAA basin by 25% or greater compared to a ten-year, pre-Best Management Practices (BMP) baseline period which spans from 1978 to 1988.

Best Management Practices plans are approved through the regulatory program and are implemented by individual permittees. The SFWMD ensures that BMP plans between different permittees are consistent and comparable. To accomplish this task, a system of BMP “equivalents” was developed by assigning points to BMPs. The BMPs are divided into three basic categories consisting of water management, nutrient management, and sediment controls. Farms differ in their water management BMPs, e.g., the amount of rainfall they detain before drainage pumping is initiated. Two BMPs commonly employed by most EAA growers are soil testing and banding of P fertilizer. A second BMP that varies between farm basins is the number and type of sediment control practices. The sediment control BMPs focus on both minimizing the

transport of sediments off the farm and removing sediments from canals. The objective of this paper is to determine the long term trends in P concentrations and loads in the EAA after implementing BMPs.

Methods

The EAA Basin Monitoring

The EAA basin-level compliance determination is based on monitoring water volume and P concentrations at various inflow and outflow points defining the boundary of the sub-basins (S5A, S2/S6, S2/S7, and S3/S8) in any given water year (WY) (Figure 1). Conveyance canals serving those sub-basins are shown on map.

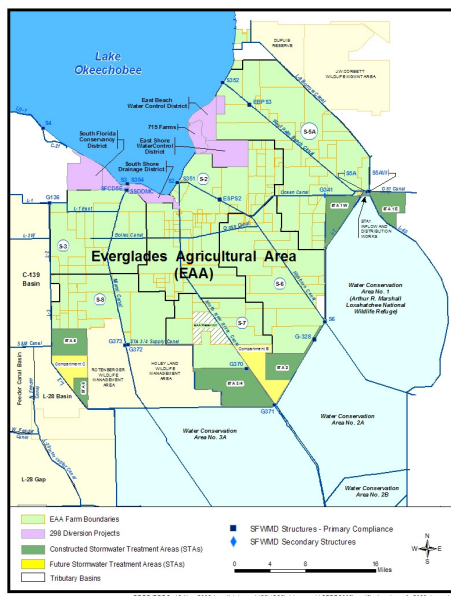


Figure 1. The Everglades Agricultural Area (EAA) basin and primary compliance water control structures used to assess load reduction performance. Water conservation areas (WCA) and storm treatment areas (STA) are also indicated. Map from SFWMD (2009).

On-Farm BMP Research Program

A comprehensive monitoring program to measure the efficacy of BMPs on water quality was initiated on ten farms in 1992 for a period ranging from 7 to 10 yr (Daroub *et al.* 2009). Monitoring was done for farm drainage volumes and P concentrations and other parameters. Six of the farm basins (00A, 02A, 03A, 04A, 08A, and 09A) had sugarcane as the major crop; the remaining four farms had mixed-cropping systems and were planted to sugarcane, sod, vegetables, and rice. For both data sets, trend analysis was conducted to determine trends over time in the basin, sub-basins and ten individual farms using seasonal Mann-Kendall analysis (Gilbert 1987; McBride 2005).

Results

Figure 2 shows the annual total P loads observed from EAA runoff for WY 1980 to WY 2008 in comparison to the target load for that year. Full implementation of BMPs started in WY 1996, and in only one instance, (WY 2007), did the observed annual total P load exceeds the target load resulting in an 18% reduction compared to baseline conditions. Overall, the current BMP program has been successful in achieving an approximate 50% long term average load reduction overall from the EAA basin and exceeding the 25% required by law (Figure 2). For Water year 2008, the total EAA outflow drainage was 76 207 ha-m with a flow weighted P concentration of 0.123 mg L⁻¹ yielding a total P load of 94 metric tons. This translated into a 44% P load reduction compared to the pre-BMP period (SFWMD 2009).

Seasonal Kendall trend analysis of aggregated monthly metrics of flow, P concentration, and P load by sub-basin and the EAA basin from 1992-2002 was conducted by Daroub *et al.* (2009) (Table 1). The data, obtained from using the SFWMD DBHYDRO database, was aggregated into hydrological basins: S5A, S6/S7, and S8 sub-basins. The outflow drainage and runoff from the sub-basins and the EAA basin had significant decreasing trends except for the S8 sub-basin (Table 1). This indicated lower drainage volumes from the sub-basins with exception of S8, probably due to shallow soils in the S8 sub-basin with less capacity to hold water. The outflow P concentrations and loads from 1992-2002 had a decreasing trend in all sub-basins except for the S6/7 which had insignificant trends.

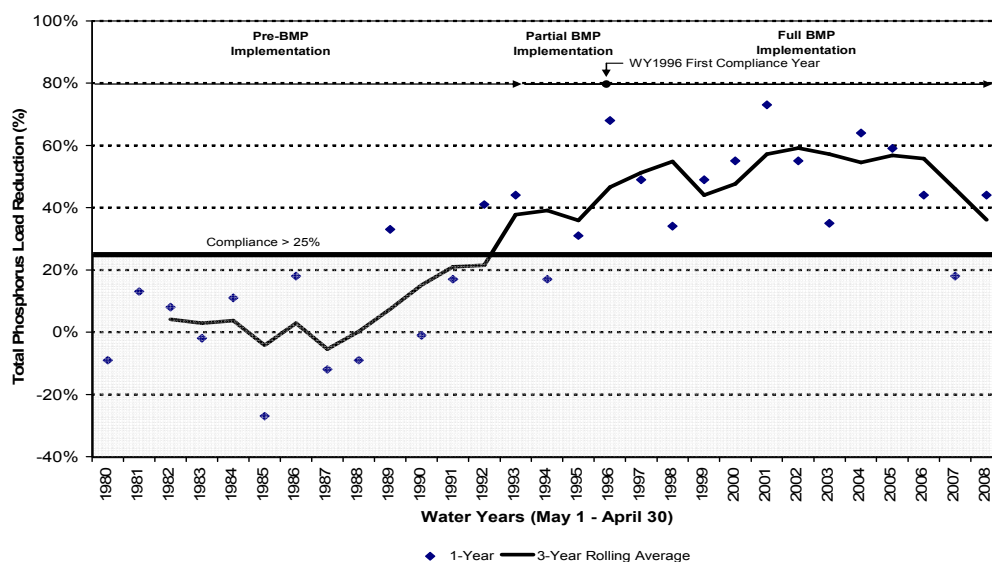


Figure 2. Annual basin-level total phosphorus load percent reduction from the Everglades Agricultural Area (Water Years 1980 – 2008). Figure from SFWMD (2009).

The decreasing trend in the S5A sub-basin is a combination of decreasing trends in P concentrations (highest negative Kendall K and z score) and drainage flow. The pronounced decreasing trends in concentration and loads indicate the success of the BMP program in the EAA. Phosphorus may have been used by the crops, retained in the soil due to adsorption (Porter and Sanchez 1992) and precipitation reactions, or retained in canal sediments (Stuck *et al.* 2001). Farm canals accumulate organic sediments rich in P from biological growth in the canals. Management practices for floating aquatic vegetation growth and dredging canal sediments control the transport of sediments and particulate P and may reduce the loads coming out of EAA farms (Stuck *et al.* 2001).

A decreasing trend was observed in monthly P unit area loads (UAL) for seven of the ten research farms but the trend was not significant for the remaining three farms (01A, 05A, and 08A) (Table 2). The farm with the highest decreasing UAL trend is 09A (highest negative Kendall K and z-score) and reflects a decrease in both drainage volume and P concentration on this farm. None of the ten farms showed increase in UAL trends. Out of the three farms that had insignificant trends in UAL, two had mixed cropping systems (01A and 05A). Farm 05A had low P, but a high volume of drainage water due to seepage problems. Farm 01A was strictly winter vegetable production, had relatively shallow soil depth, and claimed 12.7 mm rainfall detention. Vegetable production requires higher fertilizer rates and lower water tables compared to sugarcane

Table 1. Seasonal Mann-Kendall trend analysis of aggregated monthly metrics by sub-basin in the Everglades Agricultural Area from 1992-2002. Data from the South Florida Water Management District DBHYDRO database.

Basin [†]	Months	Kendall K	z-Score	z-Prob	Trend
Outflow Flow					
S5A	117	-772	-3.471	0.001	Decreasing
S6/7	117	-545	-2.448	0.014	Decreasing
S8	117	-330	-1.481	0.139	Insignificant
EAA	117	-599	-2.691	0.007	Decreasing
Outflow Concentration					
S5A	115	-1993	-4.815	0	Decreasing
S6/7	115	388	0.935	0.35	Insignificant
S8	117	-541	-2.43	0.015	Decreasing
EAA	103	-745	-2.12	0.034	Decreasing
Outflow Load					
S5A	117	-799	-3.592	0.001	Decreasing
S6/7	117	-340	-1.526	0.127	Insignificant
S8	117	-584	-2.624	0.009	Decreasing
EAA basin	117	-662	-2.975	0.003	Decreasing

Table 2. Trend analysis for monthly unit area P load (UAL) (kg P/ha) by farm location for the ten research farms in the Everglades Agricultural Area.

Site	Crops	Sub-basin	Months	Kendall K	z-Score	z-Prob	Trend
00A	Sugarcane	S5A	118	-587	-2.703	0.007	Decreasing
01A	Mixed	S6	87	-53	-0.192	0.848	Insignificant
02A	Sugarcane	S7	118	-427	-2.339	0.019	Decreasing
03A	Sugarcane	S7	118	-448	-2.001	0.045	Decreasing
04A	Sugarcane	S6	118	-560	-2.629	0.009	Decreasing
05A	Mixed	S8	90	-47	-0.314	0.754	Insignificant
06A/B	Mixed	S5A	118	-447	-1.999	0.046	Decreasing
07A/B	Mixed	S6	118	-453	-2.051	0.040	Decreasing
08A	Sugarcane	S6	110	272	1.439	0.150	Insignificant
09A	Sugarcane	S8	118	-710	-3.174	0.002	Decreasing

production. In addition, farm 01A practised summer flooding of fallow fields, which releases P from soils (Reddy 1983, Newman and Pietro 2001). The third farm that had insignificant farm P loading trend was the small sugarcane farm, 08A, which underwent several farm management changes and incorporated sweet corn as a rotational crop.

Conclusions

The BMP program implemented in the EAA farms basin-wide in 1995, as required by the EFA to reduce P loads in drainage water, is a success story. All farms in the EAA basin implement similar BMPs and basin wide P load reductions have exceeded the 25 percent reduction required by law. Trend analysis on P concentrations and loads out of the EAA basin and sub-basins showed a decreasing trend during the BMP period reflecting the success of BMPs. There are differences between farms in P load reductions probably due to cropping systems and other management and environmental factors.

References

- Daroub SH, Lang TA, Diaz OA, Grunwald S (2009) Long-term water quality trends after implementing best management practices in south Florida. *Journal of Environmental Quality* **38**, 1683-1693.
- Gilbert RO (1987) 'Statistical Methods for Environmental Monitoring'. (John Wiley and Sons: New York)
- Jones LA (1942). 'Soil, Geology, and Water Control in the Everglades Region. Bulletin **442**'. (Florida Agricultural Experiment Station).
- McBride GB (2005) Using statistical methods for water quality management, issues, problems and solutions. (John Wiley and Sons: New York).
- Newman S, Pietro K (2001) Phosphorus storage and release in response to flooding: implications for Everglades stormwater treatment areas. *Ecological Engineering* **18**, 23-38.
- Porter PS, Sanchez CA (1992) The effect of soil properties on phosphorus sorption by Everglades Histosols. *Soil Science* **154**, 387-398.
- Reddy KR (1983) Soluble phosphorus release from organic soils. *Agriculture Ecosystems and Environment* **9**, 373-382.
- Snyder GH and Davidson JM (1994). Everglades agriculture: past, present, and future. In 'Everglades, the Ecosystem and its Restoration'. (Ed SM Davis, JC Ogden) pp. 85-115. (St. Lucie Press: Delray Beach, FL)
- Stephens JC (1956) Subsidence of organic soils in the Florida Everglades. *Soil Science Society of America Proceedings* **20**, 77-80.
- Stuck JD, Izuno FT, Campbell KL, Bottcher AB, Rice RW (2001) Farm-level studies of particulate phosphorus transport in the Everglades Agricultural Area. *Transactions of the American Society of Agricultural Engineers* **44**, 1105-1116.
- SFWMD (2009) South Florida Environmental Report. (South Florida Water Management District: West Palm Beach, FL). www.my.sfwmd.gov/portal/page/portal/pg_grp_sfwmd_sfer/pg_sfwmd_sfer_home.

Performance of Systematic Approach to Nutrient Management to Improve Maize Productivity in Tamil Nadu, India

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Abstract

Maize and maize-based cropping systems are becoming important for food and nutritional security in Tamil Nadu. However, there are wide yield gaps between different locations mainly due to inadequate and imbalanced fertilizer use. A systematic approach was employed to evaluate inherent fertility and nutrient deficiencies in a wide range of soils with considerable variability and to establish the guidelines for nutrient application rates to optimize crop production and profitability. Nutrient sorption and greenhouse experiments indicated that N, P, K, and Zn were the most limiting nutrients for maize growth in the State. The optimum nutrient treatment (ONT) established through a systematic approach helped in obtaining a 20% yield gain over the State fertilizer recommendation practices with a net benefit-cost ratio of 2.52.

Key words

Systematic approach, Optimum Nutrient Treatment, Fertilizer recommendations, Profitability.

Introduction

Maize is the third most important cereal crop after rice and wheat in India and is cultivated on 8.11 million (M) ha. Total maize production is 19.77 M t, with an average yield of 2,435 kg/ha in 2007-08 (DMR, 2008). Maize is a non-traditional crop in Tamil Nadu, cultivated on 0.18 M ha, with a production of 0.29 M t and an average productivity of 1,552 kg/ha, which is 64% of the national average (Season and Crop Report, 2005). This yield gap is mainly due to inadequate and imbalanced fertilization and lack of distinct fertilizer recommendations for the various varieties and hybrids grown. There is significant opportunity for maximizing maize yields to meet the ever increasing feed grain demand by the growing livestock industry in the state.

The systematic approach to assessing plant nutrient deficiencies involves the determination of prevailing soil nutrient disorders through laboratory sorption studies and greenhouse experiments prior to conducting field experiments (Portch and Hunter 2002). There is flexibility in this approach for repeating relatively inexpensive greenhouse experiments in case there is any need for further clarification of any nutrient disorders detected. Field experiments conducted in the final phase enables confirmation of screening results from the laboratory and greenhouse studies and helps in generating optimum nutrient recommendations for the test crop under various field situations.

Methods

Experiments were conducted in seven different soil series, viz., Irugur (Igr) series (sandy clay loam, Typic Haplustalf), Palaviduthi (Pvd) series (sandy clay loam, Typic Rhodustalf), Palladam (Pld) series (sandy clay loam, Lithic Haplustept), Thulukkanur (Tlk) series (Gravelly sandy loam, Typic Haplustept), Mayamankuruchi (Myk) series (Clay, Typic Haplustept), Peelamedu (Plm) series (Clay, Typic Haplustert), and Madhukur (Mdk) series (sandy clay loam, Udic Haplustalf). All series represented dominant soil types where maize is grown. Initial soil analysis data indicated that the Igr, Tlk, Pvd, and Pld soil series had an alkaline pH and were non-saline in nature. Organic C and available N, P, and Zn were low in most of the soil series. But secondary nutrients (Ca, Mg, and S) and micronutrients Cu, Mn, and Fe were in the sufficient range.

We conducted nutrient sorption studies by adding a specific amount of the plant nutrient in solution to a specific volume of soil and allowing it to incubate for 72 hours in a dust-free environment. The air-dried sample was then analyzed for the respective nutrient elements. Sorption curves were drawn for each nutrient by plotting the amount of nutrient extracted on the Y axis against the amount of nutrient added on the X axis. The optimum nutrient treatment for the greenhouse experiment was defined for each experimental soil based on the nutrient fixation characteristics. Then greenhouse experiments were carried out using sorghum (var.

CO 29) as the test crop. The data from the sorption and greenhouse studies were used in subsequent field experiments conducted at different locations representing all seven soil series. The fertilizer rates were calculated to bring the desired level of each nutrient to the optimum level for crop growth (Table 1). Four rates of N, P, and K in selected combinations, along with a single rate of Zn, were tested using three replications in a randomized block design.

Table 1. Fertilization rates for the Optimum (ONT) and State recommendation (SR) treatments used at each experimental site.

Treatments	N-P ₂ O ₅ -K ₂ O-Zn, kg/ha						
	Igr	Tlk	Pvd	Pld	Plm	Myk	Mdk
ONT	200-54-80-8	200-76-75-11	200-76-88-7.4	200-80-85-6	200-60-25-10	200-64-48-4.8	200-70-152-9.6
SR	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5	135-62.5-50-5.5

Results

Nutrient sorption and greenhouse experiments indicated that N, P, K, and Zn were the most limiting nutrients for maize growth. Use of the optimum nutrient treatment resulted in a dry matter yield which varied from 1.94 to 2.51 g/pot, with an average of 2.17 g/pot across the different soil series (Table 2). Relative yields were 57, 63, 71, and 75% of the optimum when N, P, K, and Zn were omitted. No significant yield reductions were noticed with other nutrients, indicating that only N, P, K, and Zn required further investigation to establish the nutrient requirement of maize under field conditions.

In the field experiments averaged over the seven different soil series, maize yields of 7.2 t/ha were obtained with the application of N, P₂O₅, K₂O, and Zn at the rates of 200, 69, 79, and 8 kg/ha, respectively (Table 3). Omitting any of these nutrients from the optimum dose adversely affected crop yield indicating that N, P, K, and Zn were crucial to maize production at the experimental sites.

The grain yield of maize obtained with the optimum nutrient treatment (ONT) treatment was 7.2 t/ha as compared to 6 t/ha under the State recommendation (SR), a yield advantage of 20% or more for 6 out of 7 soil series (Table 3). Economic comparisons were calculated based on the cost of crop inputs, labour, and the value of harvested grain and stover (Table 4). The optimum nutrient levels developed using the ASI method for hybrid maize proved beneficial to farmers as this approach resulted in a calculated net income of Rs.35,000/ha, versus Rs.23,200/ha with the SR. This approach further resulted in a benefit-to-cost ratio of 2.52 with ONT, versus 2.11 obtained with the adoption of the SR.

Table 2. Response of CO 29 sorghum in a greenhouse nutrient survey

Treatments	Dry matter yield, g/pot							Mean
	Igr	Tlk	Pvd	Pld	Plm	Myk	Mdk	
ONT	1.94 (100)	2.48 (100)	1.98 (100)	1.99 (100)	2.51 (100)	2.24 (100)	2.03 (100)	2.17 (100)
ONT-N	1.23 (63)	1.32 (53)	1.13 (57)	1.13 (57)	1.36 (54)	1.33 (59)	1.12 (55)	1.23 (57)
ONT-P	1.46 (75)	1.47 (59)	1.22 (62)	1.23 (62)	1.43 (57)	1.45 (65)	1.2 (59)	1.35 (63)
ONT-K	1.62 (84)	1.76 (71)	1.38 (70)	1.33 (67)	1.74 (69)	1.64 (73)	1.31 (65)	1.54 (72)
ONT-Zn	1.25 (64)	1.85 (75)	1.52 (77)	1.54 (77)	1.88 (75)	1.75 (78)	1.58 (78)	1.62 (75)
Control	0.52 (27)	1.02 (41)	0.59 (30)	0.68 (34)	1.99 (43)	0.92 (41)	0.75 (37)	0.92 (36)
SEd	0.06	0.07	0.06	0.06	0.1	0.09	0.08	
CD (0.05)	0.12	0.13	0.12	0.11	0.2	0.19	0.17	

Data in parenthesis represents relative yield (%)

CD denotes the critical difference

Table 3. Grain yield of maize for several soil series of Tamil Nadu

Treatments	Grain yield, kg/ha							Mean over locations
	Igr	Tlk	Pvd	Pld	Plm	Myk	Mdk	
ONT	7,120	7,247	7,182	7,284	7,209	7,265	7,210	7,217
ONT-N	3,125	3,200	3,150	3,252	3,498	3,218	3,163	3,229
ONT-P	3,640	3,764	3,720	3,822	4,085	3,782	3,740	3,793
ONT-K	3,887	3,930	3,873	3,975	3,546	3,948	3,926	3,869
ONT-Zn	5,675	5,840	5,748	5,850	5,952	5,858	5,785	5,815
ONT (125% N)	7,805	7,987	7,712	7,814	8,147	8,005	7,908	7,911
SR	5,895	6,058	5,920	6,022	6,110	6,076	5,975	6,008
Control	2,598	2,786	2,667	2,769	2,886	2,804	2,698	2,744
SEd	321	328	109	329	96	118	115	
CD (0.05)	664	677	224	679	197	244	237	

Table 4. Unit cost of inputs and produce

S. No.	Particulars	Units	Cost (Rupees)
Inputs			
1.	Maize seed (COHM -5)	1 kg	70.00
2.	Urea	1 kg	5.00
3.	Super phosphate	1 kg	4.00
4.	Muriate of potash	1 kg	4.50
5.	Zinc sulphate	1 kg	26.00
6.	Atrazine	1 kg	240.00
Labour Wages			
7.	A type (Man)	8 hrs/day	100.00
8.	B type Female (Woman)	8 hrs/day	50.00
Produce			
9.	Maize grain	1 quintal	700.00
10.	Stover	1 tonne	300.00

Conclusion

This study on optimising nutrient needs using an established systematic approach for several bench mark soils of Tamil Nadu showed improvement in maize yield and helped to identify the response of major, secondary, and micronutrients. Simplification of the approach in the future through developing models for different soil series can improve maize production, productivity, and profitability in Tamil Nadu.

References

- DMR (2008) Salient achievements of AICRP maize, Directorate of Maize Research, New Delhi, India.
Portch S, Hunter A (2002) Special Publication No. 5, PPI/PPIC China Program. pp. 1-62.
Seasons and Crop Report (2005) Directorate of Economics and Statistics. Government of Tamil Nadu.

Valuing environmental externalities associated with oasis farming in Alxa, China

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Abstract

The size of agriculture's environmental footprint is increasing due to the over-exploitation of surface waters and aquifers. This study investigated physical measurements of environmental externalities for maize cropping in oasis farming, north-western China, and the monetary value of these environmental externalities, based on integrated process-based biophysical and economic modelling. The results showed that current farming practices have caused 7854 Yuan/ha of recharge groundwater cost, 7696 Yuan/ha of water treatment cost and 91 Yuan/ha of nitrous oxide mitigation cost. Although the farmer's benefit cost ratio was 1.85, the social benefit cost ratio was only 0.55. A combination of farmers' adopting optimum practices and an increase in the water price to 1.1 Yuan/m³ could maintain both the social benefit-and farmer benefit-cost ratios above 1.

Key Words

Environmental externalities, monetary valuation, oasis farming, integrated modeling, water pricing

Introduction

Recently, scientific findings have alerted the world to the increasing size of agriculture's environmental footprint. Unintended external effects, called environmental externalities, are side-effects of the economic activity and their costs are not paid for by farmers. Environmental externalities distort the market by encouraging activities that are costly to society, even if the farmer's benefits are substantial.

Valuation of environmental externalities is helpful in recognising their significance in agriculture and provides information for decision-makers to address these externalities. A few studies have been conducted on the environmental external costs of agriculture in the European countries and the USA (Lv *et al.*, 2009), and recently, Lv *et al.* (2009) valued the environmental externalities associated with rice-wheat farming in south China. Because there are no standard frameworks and methods for assessment, the results of these different studies cannot easily be compared (Pretty *et al.*, 2000). Most of these studies were either based on field-scale experimental results or statistical data.

A number of shortcomings need to be addressed if the field-scale experimental results or statistical data are employed. There noted are expressing individual farmers' behaviour using aggregated statistics and not reflecting the interactive relationships between environmental external effects and between the economic activity and environmental externalities. Modelling appears an ideal approach to understand farmers' behaviour and how farmers practices influence an agro-ecosystem. A process-based simulation model which describes in sufficient detail the dynamics of an agro-ecosystem is the most important element of the sort of modelling.

Eighteen percent of the arable land in China originates from the cultivation of grassland. Next to overgrazing, conversion to crop land, called 'oasis farming', has been the second major reason for increasingly serious grassland degradation. Alxa League, located in the north-western China, is recognised as one of the areas most seriously degraded in China. The average annual precipitation is 116 mm and potential evaporation is 20 times more than annual precipitation. There are about 20,000 ha of irrigated cropping based on 10 groundwater oases. A single season maize crop is predominantly grown because of its high yield. Due to the light texture of the soils excessive irrigation and fertiliser use result in substantial water loss through deep drainage and high concentrations of nitrate, ranging from 20 to 137 mg N/L, in groundwater.

The aim of this study was (i) to characterize the negative environmental externalities associated with maize cropping in oasis farming in Alxa; (ii) to estimate the monetary value of these negative environmental externalities; and (iii) to investigate effective policies to lessen these external costs.

Methods

Case study area

Left Banner in Alxa was chosen to represent the physical and socio-economic conditions for maize cropping in oasis farming of north-western China. Left Banner is located in the west of Alxa (37°24' -41°52' N and 103°21' -106°51' E). The soils are alluvial mixed with gray desert soils. Their physical properties are shown in Table 1. Maize cropping accounts for 70% of the oasis farming. Groundwater is the single source of irrigation water.

Table 1. Soil physical properties in Left Banner.

County	Soil layer (cm)	Particle fraction (%)			Texture (USDA)	pH	SOM (g/kg)	TN (g/kg)	TP (g/kg)	TK (g/kg)
		Sand	Silt	Clay						
Left Banner	0-30	31.4	66.5	2.1	Silt loam	8.6	1.19	0.08	0.18	21.4

Note: SOM, TN, TP, TK stand for soil organic matter, total nitrogen, phosphorus and potassium, respectively.

Physical dimension measurement of the environmental externalities

In terms of the main consequences of intensive maize cropping in oasis farming, we focused on three environmental externalities: groundwater depletion, groundwater pollution related to nitrate leaching, and nitrous oxide (N₂O) emission.

The physical dimensions of environmental externalities were simulated by process-based biophysical modelling (Li *et al.*, 2007). The model simulated the key processes of crop growth within the water and nitrogen cycles. The inputs to the model were information on the climate (air temperature, relative humidity, solar radiation and wind speed), geography (latitude, average air CO₂ concentration) and crop biological parameters (biomass-energy ratio, harvest index) and agricultural management practices (crop rotation, irrigation, fertilisation, harvest and tillage). Its outputs were biomass, crop yield, evaporation, drainage, crop nitrogen uptake, ammonia, nitrate leaching and N₂O emission. This model was developed in Fengqiu County, North China Plain and applied in Left Banner (Hu *et al.*, 2008). As Left banner is located in the middle of a desert area, it is assumed that there is no lateral groundwater recharge to the oasis. In addition, more than 90% of 116 mm precipitation falls during the growing season of maize. Therefore, groundwater depletion is calculated as the difference between irrigation applied and drainage during the growth period of maize. Nitrate leaching was obtained from modelling. When the nitrate concentration in drainage meets the water quality standard of 10 mg N/L, groundwater pollution related to nitrate leaching is considered to be zero. N₂O emission was directly obtained from the modelling.

Monetary evaluation of the environmental externalities

The restoration cost approach was used to assess the value of environmental externalities from the cropping system. This approach does not actually value the externality, but uses as a proxy the expenditure which society incurs in dealing with that negative externality. A carbon (C) tax has been frequently used in evaluating the economic loss caused by C emissions. We adopted the average rate of 142.5 Yuan/t of CO₂ and calculated the cost of N₂O emissions by multiplying the simulated emission amount by 310, the global warming potential of N₂O relative to CO₂.

When the nitrate concentration in drainage meets the water quality standard, groundwater treatment cost is zero. An average wastewater treatment cost of 1.6 Yuan/m³ was adopted in this study. There are three methods available for the restoration of groundwater subject to over-exploitation: water diversion, recharging with treated wastewater, and arranging a protected area of groundwater recharge. The cost of recharging groundwater of 1.15 Yuan/m³ was adopted, as obtained in consultation with local water resource experts, which comprehensively reflects the cost of all the above technologies and their potential application.

Simulation and evaluation of policies to avoid environmental externalities

The integrated biophysical-economic model was used to simulate the effect of different policies on the environmental externalities. The economic component was a simple farm gross margin analysis. A meta-model was used to link the biophysical model with the economic model. Crop yield was the key link between the two models. Wei *et al.* (2009a) developed the integrated economic-modelling in Fengqiu County, North China and Wei *et al.* (2009b) applied the model in Left Banner.

The potential role of provision of training and extension services was investigated as a policy measure. The maximum potential these services could provide was defined as the situation where farmers adopt the optimum practices. The optimum practices are considered to be the cases when farmers obtain the maximum yield and input resources are used most efficiently, which happens when farmers have all the knowledge needed for their farming activities. Then water pricing was investigated. The water price was increased from the present 0.1 to 2.0 Yuan/m³ in incremental steps of 0.1. The benefit-cost analysis, as the policy analysis assessment tool, was conducted on both the society and farmers. The social benefit was specified as the crop output. The farmer benefit was the social benefit plus the subsidies from the government minus taxes, if they existed. The farmer cost was specified as the sum of irrigation cost, fertilizer cost, all other variable cost and all taxes (for details, see Wei *et al.*, 2009a). Social cost was specified as the farmer cost minus the taxes plus the groundwater over-exploitation cost, groundwater treatment cost, and N₂O mitigation cost.

Results

With current practices, there is substantial groundwater depletion and the amount of nitrate leached is more than the applied nitrogen (Table 2). These physical environmental externalities, expressed in monetary terms, represent 7854 Yuan/ha for the cost of recharge groundwater, 7686 Yuan/ha for water treatment cost, and a much smaller cost for N₂O mitigation (Table 3). From the perspective of farmers, the current farming activities are viable. However, the social benefit cost ratio is only 0.55, so that these farming activities are not sustainable from the viewpoint of the society.

Table 2. Physical measures of the environmental externalities.

Practices	Irrigation applied (mm/ha)	Irrigation times	Nitrogen applied (kgN/ha)	Nitrogen application times	Yield (kg/ha)	Groundwater depletion (mm/ha)	Nitrate leached (kg N/ha)	N ₂ O emission (kg N/ha)
Current practices	1164	6	320	3	11606	683	436	2.1
Optimum practices	967	9	0	0	14213	837	71	0.35

Table 3. Economic measures of the environmental externalities.

Practices	Farmer's benefit cost ratio	Social benefit cost ratio	Recharge groundwater cost (Yuan/ha)	Water treatment cost (Yuan/ha)	N ₂ O mitigation cost(Yuan/ha)
Current practices	1.85	0.55	7854	7696	91
Optimum practices	2.77	0.88	9625	2080	15

At optimum practices, when farmers decrease irrigation amounts, increase irrigation times for 6 to 9 and do not apply nitrogen, nitrate leaching will be reduced from 436 to 71 kg N/ha, while the crop yield will increase by 2607 kg/ha (Table 2). At the optimum practices, the water treatment cost will decrease from 7696 to 2080 Yuan/ha and N₂O mitigation cost will decrease by 76 Yuan/ha, although the groundwater depletion cost will increase by 22.5% due to the deceased drainage. The farmer's benefit cost ratio will improve from 1.85 to 2.77 while the social benefit cost ratio increased from 0.55 to 0.88 (Table 3). This is indeed a win-win scenario. However, from the perspective of the society, the social benefit cost ratio should be at least 1, so further policy incentives are needed.

The effect of water pricing as a policy measure was simulated by the integrated economic-biophysical model (Figure 1). When the water price is increased to 1.1 Yuan/m³ both the social and farmer benefit cost ratio would be larger than 1. That means the farming activities are feasible from the perspective of both the society and farmers. However, under this condition, the groundwater recharge cost is still very large at 8556 Yuan/ha (Table 4). Figure 1 also shows that only a small improvement in the social benefit cost ratio results from a substantial decrease in the farmer's benefit cost ratio, demonstrating that water price is very inelastic for the social benefit cost ratio.

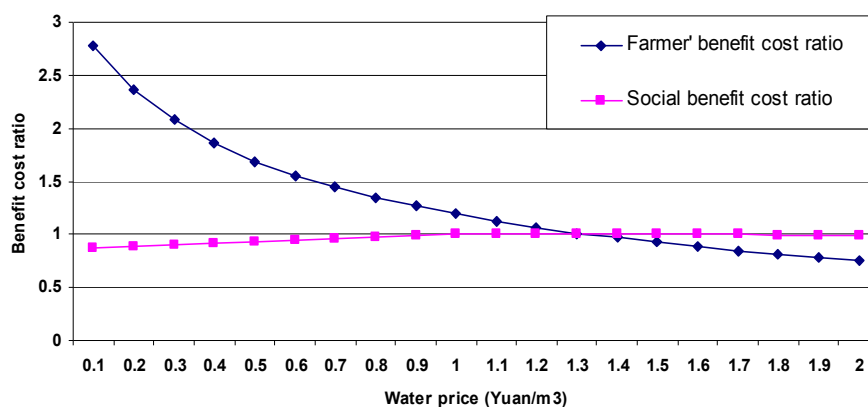


Figure 1. Effect of water price increases on farmer's benefit cost ratio and social benefit cost ratio.

Table 4. Physical measures and monetary measures of environmental externalities when both the social and farmer' benefit cost ratio are larger than 1.

Water price (Yuan/m³)	Crop yield (kg/ha)	Ground water depletion (mm/ha)	Nitrate leached (kg N/ha)	N ₂ O emission (kg N/ha)	Recharge ground water cost (Yuan/ha)	Water treatment cost (Yuan/ha)	N ₂ O mitigation cost (Yuan/ha)	Farmer benefit cost ratio	Social benefit cost ratio
1.1	13689	744	12.3	0.35	8556	416	15.46	1.13	1.002

Discussion and conclusions

This study investigated an approach for estimating the physical measures of environmental externalities associated with maize cropping in oasis farming of north-western China, and the monetary valuation of these externalities based on an integrated process-based biophysical and economic model. However imperfect and incomplete, the results from this study do help decision-makers to understand what the status of current farming activities is, what the environmental externalities are, how much they cost the society, and what the potential policy solutions to lessen these externalities are. It should be noted that the implementation of the recommended policy options would undoubtedly take time.

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References

- Hu KL, Li BG, Chen D, Zhang YP, Edis R (2008) Simulation of nitrate leaching under irrigated maize on sandy soil in desert oasis in Inner Mongolia, China. *Agricultural Water Management* **95**, 1180-1188.
- Li Y, White RE, Chen D, Zhang JB, Li BG, Zhang YM, Huang YF, Edis R (2007) A spatially referenced water and nitrogen management model (WNMM) for irrigated intensive cropping systems in the North China Plain. *Ecological Modelling* **203**, 395-423.
- Lv Y, Gu SZ, Guo DM (2009) Valuing environmental externalities from rice-wheat farming in the lower reaches of the Yangtze River. *Ecological Economics* (in press).
- Pretty JN, Brett C, Gee D, Hine RE, Mason CF, Morison JIL, Raven H, Rayment MD, van der Bijl G (2000) An assessment of the total external cost of UK agriculture. *Agricultural Systems* **65**, 113-136.
- Wei YP, Davidson B, Chen D, White R (2009a) Balancing the economic, social and environmental dimensions of agro-ecosystems: an integrated modelling approach. *Agriculture, Environment and Ecosystems* **131**, 263-273.
- Wei YP, Chen D, Hu KL (2009b) Policy incentives for reducing nitrate leaching from intensive agriculture in desert oases of Alxa, Inner Mongolia, China. *Agricultural Water Management* **96**, 1114-1119.