19th World Congress of Soil Science

Division Symposium 3.1
Precision techniques for land use

Soil Solutions for a Changing World,

Brisbane, Australia

1 – 6 August 2010

Table of Contents

A method for mapping the spatial variability of soil physical quality

Marcos B. Ceddia[A], André L. O. Villela[B], Carlos A. A. Varella[A] and Sidney R. Vieira[C]

[A]Universidade Federal Rural do Rio de Janeiro (UFRRJ), RJ, Brazil, Email ceddia@ufrrj.br;
[B]MSc. Universidade Federal Rural do Rio de Janeiro (CPGA-CS), RJ, Brazil, Email villelandre@gmail.com;
[C]Instituto Agronômico, Campinas, SP, Brazil, Email sidney@iac.sp.gov.br.

Abstract
The objective of this work was to propose a method for mapping the spatial variability of soil physical quality. Basically, the method consisted of mapping the spatial variability of Easily Available Water (E.A.W.), Air Filled Porosity (P.A.) and soil Penetration Resistance (R.P.), using geostatistics, and a standard vector classifier, to scale the physical attributes and classify the Soil Physical Quality (S.P.Q.). The studied site was an area of 6.24 ha pertaining to an Integrated Agroecological Production System (IAPS), located at Seropédica, Rio de Janeiro/BR. A regular georreferenced grid was used to assess and determine the physical attributes E.A.W., P.A. and R.P., respectively, at 0.10, 0.20 and 0.30 m soil depth. The classes of S.P.Q. used were: Restrictive (E.A.W.<3.9 mm, and/or P.A.<10%, and/or R.P.>2mPa), Suitable (E.A.W. = 3.9-5.5 mm, and P.A. = 10-20%, and R.P.=1-2 MPa) and Optimum (E.A.W. > 5.5 mm, and P.A.>30%, and R.P.< 1MPa). All physical attributes presented spatial dependence with fitted spherical (E.A.W. and P.A.) or exponential (R.P.) semivariograms models. Most part of the area was classified as restrictive, at all depth for the sake of low E.A.W., followed by suitable and Optimum, respectively. The method must be tested in different environmental conditions.

Key Words
Management zones, precision agriculture, geostatístics, multivariate analysis, euclidian distance.

Introduction
The knowledge of the spatial variability of soil physical quality of an area is frequently necessary to improve the management of agriculture production systems. Recently, the Least Limiting Water Range (LLWR) has been proposed and used as an index of soil physical quality for crop growth (Silva *et al.* 1994), since it integrates the effects of soil aeration, resistance to penetration, and soil water retention on crop growth into a single attribute. Despite the advantage of using this index, the process of its measurement in a specific site is too expensive and time consuming, especially in projects aiming to map the spatial variability of soil physical quality in precision agriculture. Considering this limitations, the objective of this work was to propose a more cost-effective method for mapping the spatial variability of soil physical quality.

Material and methods
The study site is 6.24 ha hectares and is located between 43º40'00" and 43º 41'10" W, and 22º44'30" and 22º45'30" S, in Seropédica municipality, Rio de Janeiro. The area is composed by glebes, 5.05 ha managed in a mixed farming system, and pasture, 2.89 ha, it was implanted in 1997 and farmed exclusively to the grass Transvala (Digitaria decumbens Stent cv Transvala). In order to apply geostatistics to investigate the spatial variability of soil physical attributes, the sampling strategy included the definition of a regular square grid with 20 meter spacing. As recommended by Trangmar *et al.* (1985), since spacing between sampling points might affect data modeling, additional soil samples were collected in reduced spacing (1, 5 and 10 meters), according to topography and soil classes. A grid with 169 points were performed, where altitude and coordinates (UTM system) were measured using a GPS with differential correction (DGPS- Trimble-GeoExplorer 3 model), with submeter accuracy. In 122 georreferenced points, undisturbed soil samples were collected at depths 0.0–0.10, 0.10–0.20 and 0.20-0.30m, for the determination of water retention at 10 kPa (Field Capacity) and 80 kPa (limit of tensiometer reading) and soil bulk density - ρ_b (EMBRAPA 1997). Thereafter, the soil samples were grinded and air-dried for determination of soil particle density (ρ_s) and soil particle size distribution (Pipette method) (EMBRAPA 1997). Easily Available Water (EAW) and Air-Filled Porosity (PA) were calculated by the expressions, E.A.W. = (θ_{10kPa}- θ_{80kPa}) and P.A. = ($\theta_{total\ porosity}$ - θ_{10kPa}), respectively. Penetration resistance (PR) was determined in 169 grid points, at 0.0-0.10, 0.10-0.20 and 0.20-0.30m soil depth, using a penetrometer of impact developed by Stolf (1991). Geostat (Vieira *et al*. 1981) software was used both to determine measures of spatial continuity (experimental semivariograms) and for experimental data modeling, by fitting data to an analytical model to be further used in the estimation and

simulation stages. The selection of the most suitable analytical model was done by cross-validation (jack knifing). The kriged estimation of EAW, PA and PR, in each soil depth, were used to classify the Soil Physical Quality (SPQ) as: 1- Restrictive (E.A.W.<3.9 mm, and/or P.A.<10%, and/or R.P.>2mPa), 2- Suitable (E.A.W. = 3.9-5.5 mm, and P.A. = 10-20%, and R.P.=1-2 MPa) and, 3- Optimum (E.A.W. > 5.5 mm, and P.A.>30%, and R.P.< 1MPa). The integration of each soil attribute (EAW, PA and PR) on classes of SPQ was performed on Matlab software, using the Euclidian distance of each point in relation to a standard vector (Restrictive, Suitable and Optimum).

Results and discussion

Figure 1 shows the semivariograms of E.A.W., P.A. and P.R., at 0.10, 0.20 and 0.30m soil Depth. All the attributes present spatial dependence and the Spherical model was best fitted to the attributes E.A.W. and P.A. at all depth, and P.R., at 0.10m depth. The Exponential model was best fitted to P.R. at 0.20 and 0.30 m soil depth. Considering the spatial dependence index proposed by Cambardella *et al*. (1994), all the attributes presented strong spatial dependence (C_0/C_o+C_1< 25%) at all depth, with exception of P.R and E.A.W. at 0.10m soil depth. It was observed that the nugget effect, for all the attributes, decreased as the soil depth increase. This behavior is probably associated to the pedogenetic process commonly occurring in the soil of the study site. Up to 0.30 m soil depth, the clay content increase forming an argilic horizon and reduces the erratic component of the semivariance.

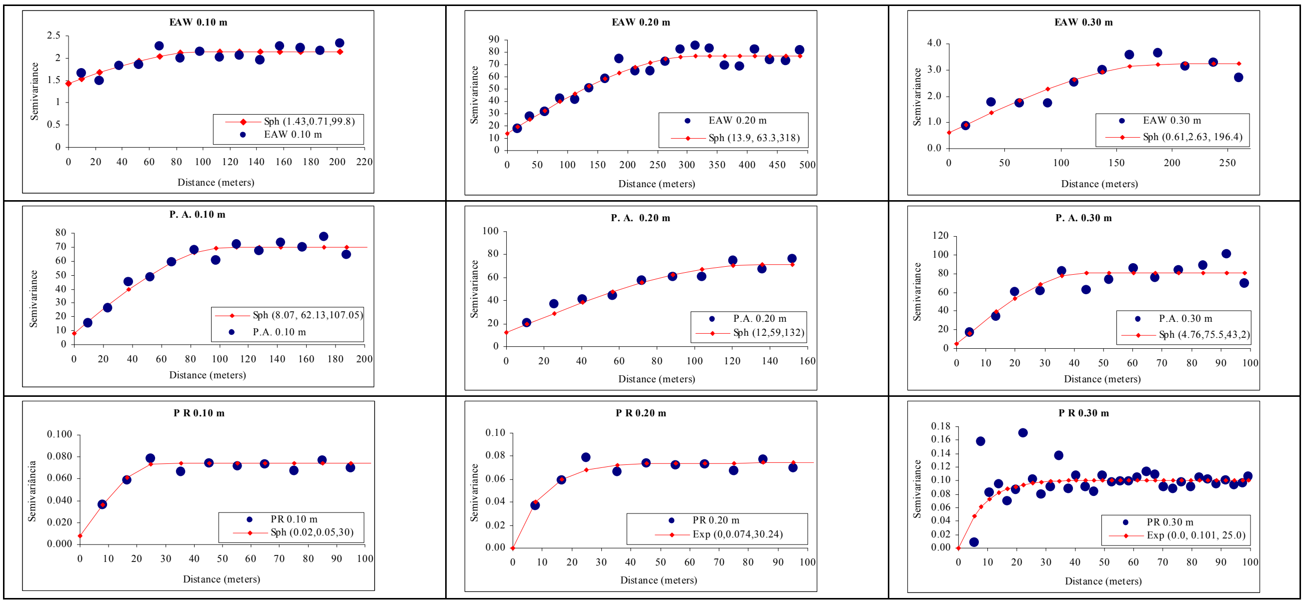


Figure 1. Semivariograms of E.A.W., P.A. and P.R. at 0.10, 0.20 and 0.30 m soil depth.

Figure 2 shows the spatial variability maps of S.P.Q. at 0.10, 0.20 and 0.30 m soil depth. At all depth, the restrictive class represented the most part of the area and increase according to the soil depth (56, 64 and 68%, respectively). The higher percentage of restrictive class was caused by the low values of E.A.W. of the study site, mainly at the 0.10 m soil depth. On the other hand, as the soil depth increase, the P.R. increase and reduced the occurrence of optimum class (30, 15 and 13%, respectively).

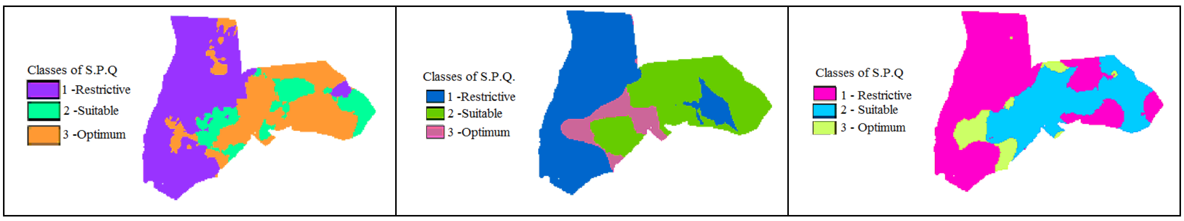


Figure 2. Spatial variability maps of Soil Physical Quality at 0.10 , 0.20 and 0.30 m soil depth.

Conclusions

The most part of the study site presented a restrictive S.P.Q. due to the low values of EAW. The proposed method was efficient to classify the soil physical quality of the study site, and must be tested in different environmental conditions.

References

Cambardella CA (1994) Field scale variability of soil properties in central Iowa soil. *Soil Science Society of America Journal* **47,** 1501-1511.

EMBRAPA Empresa Brasileira de Pesquisa Agropecuária (1997) *Manual de Métodos de Análise de Solo***.** Rio de Janeiro. 247p.

Silva AP; Kay BD, Perfect E (1994) Characterization of the least limiting water range. *Soil Science Society of America Journal* **58,** 1775-1781.

Stolf R (1991) Teoria e teste experimental de fórmulas de transformação dos dados de penetrômetro de impacto em resistência do solo. *Revista Brasileira de Ciência do Solo* **15**(2), 229-35.

Trangmar B, Yost R, Uehara G. (1985) Application of geostatistics to spatial studies of soil properties. *Advances in Agronomy* **38,** 45-93.

Vieira S, Nielsen D, Beggar J (1981) Spatial variability of field measured infiltration rate. *Soil Science Society of America Journal* **45,** 1040-1048.

Analysis of potential benefits of precision irrigation for variable soils at five pastoral and arable production sites in New Zealand

Carolyn Hedley[A], Ian Yule[B] and Stu Bradbury[C]

[A]Landcare Research, Riddet Road, Massey University Campus, Palmerston North 4474, NZ, Email hedleyc@landcareresearch.co.nz
[B]NZ Centre for Precision Agriculture, Massey University, Palmerston North, NZ, Email i.j.yule@massey.ac.nz
[C]Precision Irrigation, 581 Taonui Rd, RD5, Feilding, NZ, Email stu@precisionirrigation.co.nz

Abstract
The potential benefits of modifying irrigation according to soil differences under one irrigation system have been assessed for five production sites for the period 2004–2008. A simulated analysis used a soil water balance to compare hypothetical uniform rate irrigation (URI) with variable rate irrigation (VRI) scheduling for four irrigation seasons (2004–2008). URI applies irrigation to the whole area when the most droughty soil zone reaches a critical soil moisture deficit, whereas VRI only applies irrigation to the soil zone that has reached its critical soil moisture deficit. The method has developed digital soil water status maps from spatially located soil apparent electrical conductivity (EC_a) data regressed against soil available water-holding capacity (AWC) ($R^2 \geq 0.8$ at 4 sites), with a daily time step added using a soil water balance model (Hedley and Yule 2009). These maps are available for upload to a fully automated variable rate irrigation system (Bradbury 2009). Water-use efficiency indicators show that potential water savings with VRI are 8–21%; drainage and runoff was reduced 19–55%, and cost savings were estimated at NZ$51–NZ$150 per hectare.

Key Words
EM mapping, AWC map, soil water status, variable-rate irrigation.

Introduction
Precision irrigation of variable soils is a soil-based strategy for improved use of global freshwaters and soils, addressing global food security issues, because agriculture accounts for 70% of global water use and more than a third of the world's food requires irrigation for production (Goodwin and O'Connell 2008). Such strategies to conserve natural capital, are required to meet the 21st century's global food security challenge (Lal 2009).In New Zealand, sprinkler systems now compose at least 40% of all irrigation systems, and often traverse highly variable soils (e.g. the silty, sandy and stony soils of the Canterbury Plains). Therefore studies were initiated to investigate the potential benefits of a soil-based decision support tool for variable rate irrigation of variable soils (Hedley and Yule 2009). In addition, Bradbury (2009) has developed a variable rate modification of existing sprinkler systems that fits each sprinkler with a latching solenoid valve that is pulsed either on or off by a node. Each node is part of a wireless network: it provides individual control of four sprinklers and receives wireless inputs from a central controller to guide variable water delivery (Bradbury 2009). New Zealand uptake of this technology has been for several reasons; and once installed these VRI systems have multiple benefits including control of soil water status in the optimum range for plant growth. The system differs from the air-actuated valve VRI system of Han et al. (2009), also described by Perry *et al*. (2002), because it does not require a compressed air-line, and every sprinkler is controlled individually. The New Zealand VRI customised software allows upload of the soil water status maps developed for spatial irrigation scheduling (Hedley and Yule 2009).VRI is best suited to centre pivot and lateral sprinkler irrigation systems, which have high application accuracy, and sprinkler line design well suited to individual sprinkler control. Other forms of irrigation, such as drip irrigation, are used where water is more severely limited, and/or land productivity is less, and there are potential applications for similar support tools for these systems. This research paper uses water use efficiency indicators to analyse potential benefits of VRI scheduling on variable soils at five production sites.

Methods
Site Selection
The five sites were:

Site 1: 156 ha Manawatu pastoral site on alluvial and high terrace loessial soils
Site 2: 40 ha Canterbury dairy pastoral site on alluvial outwash gravelly soils
Site 3: 22 ha Manawatu maize grain crop on sand plain and dune soils
Site 4: 35 ha Manawatu maize grain crop on alluvial terrace soils
Site 5: 24 ha Ohakune potato crop in mixed volcanic air-fall and water-borne tephric soils

EMI survey and soil EC_a map production, with characterization of soil zone AWC

An on-the-go electromagnetic induction (EMI) mapping system was used to collect simultaneous high resolution (≤ 12 m) positional and soil apparent electrical conductivity (EC_a) data. Each EC_a map was then used for field investigation of soil differences, and on the basis of these differences, topography and practical management implications, the EC_a zones were divided into a smaller number of soil management zones (3−4), using Geostatistical Analyst (ArcGIS, ESRI). Soil samples were collected from each of these zones (≥ 3 replicates) to characterize zone AWC (defined as the soil moisture difference between field capacity [FC] and wilting point), (Hedley and Yule 2009).

Hypothetical irrigation scheduling for VRI and URI

A soil water balance model (Allen *et al*. 1998) was used to track soil wetting and drying patterns of individual soil management zones, for updating the AWC maps. Model inputs are: AWC, evapotranspiration (Et), capillary rise, rainfall and irrigation. The model determines root zone soil water depletion relative to FC (mm), on any one day. Site-specific rainfall was used, and reference Et was estimated using the FAO Penman-Monteith equation for a uniform grass sward. Reference Et was adjusted for crop type and stage at the irrigated maize and potato sites to provide crop Et. A dual coefficient model for crop Et was used, which assesses soil evaporation separately from crop transpiration. This is important under the frequent irrigation events which continually rewet the soil surface. Capillary rise, C, was assumed to be zero when the water table was >1m below the base of the root zone. Otherwise its contribution was calculated (Scotter 1989) and added to AWC to provide an effective AWC (EAWC). Irrigation events (10 mm) were scheduled on the day that zone critical soil moisture deficit (CSMD) for irrigation was reached (depletion factor of 0.5AWC [pasture]; 0.55AWC [maize]; 0.35AWC [potatoes]). URI scheduled an irrigation event (10 mm) to the whole area when the zone with smallest AWC reached its CSMD. VRI scheduled irrigation events to specific zone CSMD, making better use of soil profile water storage, and also maintaining potential yield.

Water use efficiency (WUE) indicators

The following WUE indicators were used to assess the potential benefits of VRI compared with URI:

Amount of irrigation water used (mm/season)

Amount of drainage and runoff during the period of irrigation and whole year (mm/season)

Cost saving (based on a typical cost of irrigation: NZ$2/mm/ha; FAR 2008).

Irrigation water-use efficiency (IWUE) is calculated as the kg of increased dry matter production ($Yield_{irrig}$ – $Yield_{non\text{-}irrig}$) per mm of irrigation water applied. Actual or typical regional yields have been used in this calculation.

Energy use is calculated as kg $CO_{2\text{-}eq}/m^3$ of irrigation water applied. A factor of 0.50 kWh/m^3 irrigation water pumped is used based on data reported in New Zealand literature (e.g. FAR 2008). The conversion factor of 0.18 is then used to convert kWh to kg $CO_{2\text{-}eq}$ (MED 2008).

Nitrogen leaching was estimated at three sites using the nutrient budgeting model Overseer Version 5.4.3 (AgResearch® 2009) for pasture, and biophysical models AMaizeN (Li 2006) and The Potato Calculator, (Jamieson *et al*. 2004). These models simulate crop growth using site-specific climate, soil and crop production inputs; with N leaching below the root zone (kg N/ha) being one output. The depth of the root zone was set at 0.6 m for pasture and potatoes, and 1.5 m for maize.

Results

Significant differences in zone AWC were found at all sites (Table 1). Soil AWC was regressed against soil EC_a at Sites 1-4 ($R^2 \geq 0.8$), and prediction models were developed to produce soil AWC maps. Soil EC_a is controlled by soil moisture and texture differences at Sites 1 and 4. At Site 2, soil EC_a is controlled primarily by percent stones. At Site 3, it reflects soil moisture differences, with capillary rise supplying additional water for plant use in Zone 2 and 3. The amount of additional water supplied above AWC was estimated using a relationship developed by Scotter (1989) for these sand soils. At Site 5, a field investigation of the EC_a-defined soil zones revealed three distinctly different soil parent materials in a complex soil pattern of air-fall and water-borne volcanic materials. At this site, soil AWC was significantly different between zones (Table 1), so that zone management could be used for irrigation scheduling.

Table 2 gives AWC range at any one site and reports a summary of comparisons of WUE indicators for URI and VRI. The amount of irrigation water saved using VRI varied between 8 and 21% per year (mean of 4 years, 2004–2008) being greatest at Site 3, where additional water is contributed via capillary rise from a seasonally high water table at different rates to the different zones (Table 1). VRI conserves more water in

Table 1. Soil texture and effective AWC of EC_a-defined zones (standard deviation in brackets, n=3).

Site	Soil texture	EC_a (mS/m)	Capillary Rise (CR) (mm)	EAWC (AWC + CR)* (mm root/zone)
Site 1 – Manawatu pasture (on Alluvial and High terraces soils)				
Zone 1	Loamy gravel	14.0–20.0	0	77 (9) a
Zone 2	Sandy loam	20.0–30	0	99 (6) a b
Zone 3	Silt loam	30.0–37.0	0	124 (28) b c
Zone 4	Silt loam	37.0-65.0	0	132 (16) c
Site 2 – Canterbury dairy pasture (on Alluvial terrace soils)				
Zone 1	Very stony sandy loam	12.5–13.6	0	44 (6) a
Zone 2	Stony sandy loam	13.7–14.6	0	74 (19) a
Zone 3	Sandy loam	14.7–16.7	0	101(6) b
Site 3 – Manawatu maize grain (on Sand plains and dune soils)				
Zone 1	Sand	17.0–26.0	0	85 (6) a
Zone 2	Sand	27.0–33.0	34	214 (15) b
Zone 3	loamy sand	34.0–50.0	139	329 (17) c
Site 4 – Manawatu maize grain (on Alluvial terrace soils)				
Zone 1	Loamy sand	14.0–19.6	0	190 (10) a
Zone 2	Silt loam	19.7–22.1	0	180 (15) a
Zone 3	Mottled silt loam	22.2–27.5	0	105 (21) b
Site 6 – Ohakune potato field (in mixed volcanic air-fall and water-borne tephric soils)				
Zone 1	Loamy silt	14.9–17.2	0	186 (3) a
Zone 2	Loamy sand	17.3–18.1	0	81 (12) b
Zone 3	Sandy loam	18.2–22.9	0	156 (16) c

( ) standard deviation in parentheses; *EAWC with different letters are sig. diff. at any one site ($p \leq 0.5$)

years when there is more rainfall during the period of irrigation. A wet Spring in 2006 (1/10/06 – 31/12/06) delivered 400 mm of rain to the maize grain sites, and water savings from VRI increased from the mean of 21% to 26% at Site 3, and from 12% to 14% at Site 4. Runoff (overland) and drainage (below the root zone) savings with VRI were considerable (8–26% per year; 19–55% during the period of irrigation), because delayed irrigation to some zones allows soils to reach greater soil moisture deficits with less likelihood of runoff and deep drainage. This is indicated by an improved IWUE (Table 2).

Table 2. A comparison of VRI and URI WUE indicators.

Site	Land use	EAWC range[A] mm	Irrigation water saved %	Drainage/Runoff saved during period of irrigation %	Energy saved kg CO_2-eq/ha/y	Improved IWUE kg/mm/ha	Reduced N leaching kg/ha
1	Pasture	77–132	8	19	23	2	-
2	Pasture	44–101	9	55	40	1	3
3	Maize grain	85–329	21	40	67	5	0
4	Maize grain	105–190	12	22	38	2	-
6	Potatoes	81–186	15	29	30	4	2.5

[A]EAWC = AWC + CR; EAWC range calculated for a root zone depth of 60 cm (pasture, potatoes) and 100 cm (maize grain).

Our N leaching models support the reduced drainage data under potatoes and pasture with VRI. The amount of leached N per year under dairy pastoral systems was reduced with VRI (VRI: 26 kg/ha; URI: 29 kg/ha) but is overall slightly higher than for the other two systems (maize grain VRI: 22 kg/ha; URI: 22 kg/ha; potatoes VRI 9.4 kg/ha; URI 11.9 kg/ha).

Energy savings with VRI were 23–67 kg $CO_{2\text{-eq}}$/ha/y. Saved water can be diverted elsewhere when total water allocations are restricted allowing improved overall on-farm IWUE. Assuming that it costs NZ$2/ha to pump one mm irrigation water (FAR 2008), these five case studies show a cost saving of NZ$51–150/ha.
In this study, the potential water savings and accompanying energy savings with VRI, increase with soil variability, where soil variability is defined as AWC range under one irrigation system (Figure 1). Our results suggest that where the ability of the soil to store and supply water to plants varies by about 50 mm then the potential water savings are about 8.5%; and by >100 mm gives a potential water saving of ≥15%.

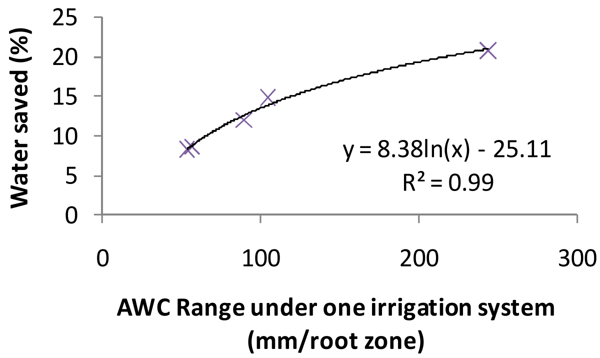


Figure 1. Relation of water saved using VRI to soil variability (defined as the difference between the smallest and largest soil AWC at each site) for five sites and a 4-yr period of study (2004–2008).

Conclusions

Increased dependence on irrigation for global food supply, and reduced availability of the global freshwater resource require irrigation systems to become increasingly more efficient. Variable soils ideally require variable timing and placement of irrigation for most efficient water use, and a precision irrigation method has been reported and assessed which schedules irrigation according to soil differences. The soil water status maps, derived from soil EC_a maps, are available for upload to a fully automated variable rate irrigation system, enabling improved water and energy use efficiency.

References

Allen RG, Pereira LS, Raes D, Smith M (1998) 'Crop Evapotranspiration Guidelines for Computing Crop Water Requirements'. (FAO Irrigation and Drainage Paper 56: Rome 2004).

Bradbury S (2009) Variable rate irrigation for centre pivot and linear move irrigators. www.precisionirrigation.co.nz/index.php.

FAR (2008) 'Water. Cost of Irrigation'. Foundation for Arable Research brochure No. 73, February 2008.

Goodwin I O'Connell MG (2008) The future of irrigated production horticulture – world and Australian perspective. *Acta Horticulturae* **792,** 449–458.

Han YJ, Khalilian A, Owino TO, Farahani HJ, Moore S (2009) Development of Clemson variable-rate lateral irrigation system. *Computers and Electronics* **68,** 108–113.

Hedley CB, Yule IJ (2009) Soil water status mapping and two variable-rate irrigation scenarios. *Precision Agriculture* **10,** 342–355.

Jamieson PD, Stone PJ, Zyskowski RF, Sinton S, Martin RJ (2004) Implementation and testing of the Potato Calculator, a decision support system for nitrogen and irrigation management. In 'Decision Support Systems in Potato Production'. (Eds DKL MacKerron, AJ Haverkort) pp. 85–99. (Academic Publishers: Wageningen).

Lal R (2009) Soils and world food security. *Soil and Tillage Research* **102,** 1–4.

Li FY, Jamieson PD, Pearson A, Arnold N (2007) Simulating soil mineral nitrogen dynamics during maize cropping under variable fertiliser management. In 'Designing Sustainable Farms: Critical Aspects of Soil and Water Management'. Occasional Report No. 20. (Eds LD Currie, LJ Yates) pp. 448–458. (Fertiliser and Lime Research Centre: Massey University, Palmerston North, New Zealand).

Ministry for Economic Development (2008) 'New Zealand Greenhouse Gas Emissions 1990–2007'. (Wellington: MED).

Perry C, Pocknee S, Hansen O, Kvien C, Velladis G, Hart E (2002) Development and testing of a variable-rate pivot irrigation control system. In 'ASAE Meeting Presentation, Chicago, Illinois, USA, Paper No. 022290.

Scotter DR (1989) An analysis of the effect of water table depth on plant-available soil water and its application to a yellow-brown sand. *New Zealand Journal of Agricultural Research* **32,** 71–76.

Agricultural utilization of the apatite-phosphorus in pyroclastic flow deposits

Yasuo M. Nakamaru[A]**,** Shuhei Tsutiya [A], Kazuma Okada[A] and Nobuhiro Izumi[A]

[A]Tokyo University of Agriculture, Faculty of Bioindustry,Yasaka 196, Abashiri City, Hokkaido 099-2493, Japan,
Email y3nakama@bioindustry.nodai.ac.jp

Abstract
In Abashiri District of eastern Hokkaido, Japan, much arable land leveled for agricultural use has subsoil layers that consist of Kutcharo pyroclastic flow deposits. These deposits in subsoil are generally firm and they inhibit the root development of arable crops. However, their available phosphorus (Truog-P) content is high (70-170 mg P_2O_5 /kg). Sources of phosphorus (P) in the pyroclastic flow deposits were previously evaluated as apatite. In 2007 and 2008, the utilization of the apatite-P in pyroclastic flow deposits in the subsoil was tried in a field cultivation experiment with sugar beet. Before the experiment, trenchers were used to thoroughly mix the pyroclastic flow subsoil with topsoil in a part of the field to promote root development (subsoil mixed plot) and the rest of the field was used as a control plot. During the cultivation, the changes of the soil available P and P uptake of sugar beet were measured. Subsoil mixing clearly improved root development. For the subsoil mixed plot, the yield of sugar was 30% higher, and the phosphorus uptake was 50% higher than the control plot in 2007. In 2008, also the increase of phosphorus uptake was observed for subsoil mixed plot although the yield was not improved. Under cultivation, it was observed that the soil Truog-P was increased and the pH was decreased in the subsoil mixed plot. These results suggested that the weathering of apatite-P in the pyroclastic flow deposits was enhanced in the subsoil mixed plot by the reaction with soil reactive Al and/or Fe and low pH condition. The weathering of apatite-P should increase the P uptake of the sugar beet. Thus the apatite-P should be an important P resource for agriculture.

Key Words
Apatite, phosphorus, pyroclastic flow deposits, sugar beet, utilization.

Introduction
In the Hokkaido region of northern Japan, much arable land has been leveled with backslope cutting and foreslope filling for large scale agriculture. This includes i) removing and storing the A horizon layer, ii) cutting and filling to create wide and gently sloping fields by grading, and iii) replacing the stored topsoil evenly to create an Ap horizon. Such procedures have made soil profiles irregular. In the Abashiri district of Hokkaido, Kutcharo pyroclastic flow deposits are widely distributed as parent material; the deposits are present at about a 40-50 cm depth from the soil surface as subsoil (Figure 1). The pyroclastic flow deposits are generally sandy and firm, so the development of crop roots in the subsoil has been inhibited (Nakamaru *et al.* 2008). Therefore pyroclastic flow deposits in the subsoil layer have been regarded as an inhibitor to agricultural production. However, it is also known that some volcanic materials such as tephras or pyroclastic flow deposits contain a significant amount of apatite phosphorus (apatite-P) (Nanzyo and Yamasaki 1998, Nanzyo 2002). Although its solubility is low (Engelstad *et al.* 1974), the existence of apatite has been reported for Pinatubo pyroclastic flow deposits in the Philippines (Nanzyo 2002), and for Unsen pyroclastic flow deposits in Japan (Nanzyo *et al.* 2003), and also for Kutcharo pyroclastic flow deposits in Abashiri area. The deposits contain 300-800 mg P_2O_5/kg of apatite-P, and 70-140 mg P_2O_5/kg has been evaluated as plant available (Nakamaru *et al.* 2008). The apatite-P is untouched phosphorus (P) resource and its utilization is important because recently the price of phosphate rock is soaring (Steven *et al.* 2008).

Apatite is ranked as an easily weathered mineral. We are trying to utilize the apatite in Kutcharo pyroclastic flow deposits in the Abashiri area. While apatite is considerably soluble in acid extracting solutions, the plant availability of apatite-P depends on many factors, such as soil conditions, types of plants and the properties of apatite (Rajan *et al.* 1996). In a previous study, it was reported that pigeon pea and chickpea could utilize apatite-P in Pinatubo pyroclastic flow deposits by releasing organic acids from their roots (Nakamaru *et al.* 2000). In our current study, we examined the apatite-P utilization of sugar beet while improving the physical properties of the pyroclastic flow deposit layer in the subsoil. Sugar beet was used as a test crop because it was one of the most important crops around Abashiri.

As the subsoil improvement method, we used a trencher to mix the pyroclastic flow deposit layer in the subsoil and topsoil layer (A horizon). Generally the trencher is used for the cultivation of Chinese yam (Dioscorea opposita naga imo strain) and edible burdock (Arctium lappa L. var. edule), and it can cultivate up to one meter depths. With the mixing of pyroclastic flow deposits and A horizon, we considered that the apatite weathering in the deposits could be enhanced by the reaction with active Al and Fe in the A horizon of Andisol. From the viewpoint of soil genesis, Walker and Syers (1976) reported that with time the apatite in the parent rocks was gradually converted into occluded, non-occluded and organic P. Because Andisol commonly contains a large amount of active Al and Fe (Shoji *et al.* 1993), the P released with apatite weathering should react with active Al and Fe in a manner similar to that described by Walker and Syers. It has also been reported that the reaction of apatite-P and active Al and Fe was promoted by an acidic condition (Nanzyo *et al.* 1997). Therefore, we investigated the weathering of apatite-P under cultivation with the changes of soil pH.

Methods

Cultivation experiment of sugar beet

A field cultivation experiment of sugar beet (Beta vulgaris ssp. vulgaris) was done in 2007 and 2008. Abashiri Experimental Farm of Tokyo University of Agriculture was used. The soil of this farm is classified as Typic Fulbudand. The experimental field had been leveled and the soil has an irregular profile. Surface soil is the A horizon of Andisol, but the soil profile has a pyroclastic flow deposit layer beginning at 40 cm from soil surface. This pyroclastic flow deposit is so firm that the fibrous root distribution of arable crops is generally limited in this layer. In 2005, trenchers were used to thoroughly mix pyroclastic flow subsoil with topsoil in a part of the field for Chinese yam cultivation, this area was used as the subsoil mixed plot and the rest of the field has been used as a control plot for the present study. Sugar beet plants were cultivated from May to October in 2007 and 2008. Before transplanting of Sugar beet the soil was fertilized using chemical fertilizer by conventional fertilization method in Abashiri area. In 2007, 17.5 kg of N, 40 kg of P_2O_5 and 11 kg of K_2O was applied, also, in 2008, 18.5 kg of N, 40 kg of P_2O_5 and 24 kg of K_2O was applied. At the harvest stage (October), sugar beet yield, the fibrous root development and the phosphate uptake were measured. The root distribution in the soil profile was determined by tracing the root in the profile onto a transparent plastic film. During the cultivation period, an auger was used to take soil samples from the field every month by dividing the soil layer into 10 cm intervals up to a depth of 90 cm. At the soil sampling, soil was sampled from three different places as replication.

For the soils sampled in May to October (the beginning of cultivation to the harvest period), pH (H_2O), acid oxalate extractable-Al, Fe (Alo, Feo) were measured. Acid oxalate extractable-Al and -Fe contents refer to the amount of Al/Fe-(hydr) oxides and Al/Fe-humus complex. They are regarded as active Al and Fe which are reactive components for phosphate adsorption (Parfitt 1978). Alo and Feo were measured by the method of Blakemore *et al.* (1981). The content of each chemical form of soil P was determined by the following methods. The soil available P amount was measured by the Truog method (Blakemore *et al.* 1981). Each chemical form of soil P (Al bound-P, Fe bound-P and Ca bound-P)was determined separately with the method of Chang and Jackson (1957).

Results

The yield and P uptake of sugar beet

The yield, plant dry weight, and P uptake of sugar beet are shown in Table 1 and 2. In 2007, the yield of sugar was 30% higher for the subsoil mixed plot than for the control plot (Table 1). Also, the P uptake of sugar beet was 50% higher for the subsoil mixed plot than the control plot (Table 2). However, in 2008, the tap root weight and the yield of sugar was lower in the subsoil mixed plot than the control plot (Table 1). This decrease of yield was possibly due to the Cercospora leaf spot (Cercospora beticola Saccardo) because the symptoms of this disease was commonly observed in the subsoil mixed plot from August to October in 2008. Also the increase of plant dry weight was smaller for the subsoil mixed plot than for the control plot from August in 2008 (Table 2). Although the yield was small, the P uptake from June to August was higher for subsoil mixed plot than the control plot in 2008 (Table 3). These results showed that the trenching procedure increased the P uptake of sugar beet by promoting the fibrous root development. Also, it was possible that the apatite-P in the pyroclastic flow deposits contributed to the increase of P uptake by sugar beet.

Table 1. The yield of sugar beet cultivated in 2007 and 2008. The values are the average of three replicated values and the standard deviation.

		Fresh tap root weight † (Mg/ha)	Sugar content† (%)	Sugar yield† (Mg/ha)
	Control	61.5±4.4	15.7±0.6	9.6±1.0
2007	Subsoil mixed	82.6±1.6	15.9±0.4	13.2±0.1
	Control	80.7±3.3	15.9±0.4	12.8±0.5
2008	Subsoil mixed	63.4±3.3	17.0±0.2	10.8±0.5

Table 2. Plant P uptake of sugar beet cultivated in 2007 and 2008. The values are the average of three replicated values and the standard deviation.

P-uptake (P_2O_5 g/plant)					
2007	2007.6.26	2007.7.24	2007.8.7	2007.9.4	2007.10.2
control	0.05±0.01	0.56±0.22	1.03±0.08	0.90±0.03	1.00±0.18
subsoil-mixed.	0.06±0.003	0.66±0.04	1.38±0.20	1.73±0.25	1.45±0.24
2008	2008.6.19	2008.7.17	2008.8.22	2008.9.24	2008.10.22
control	0.07±0.02	0.29±0.07	0.46±0.07	0.72±0.28	1.03±0.04
subsoil-mixed.	0.05±0.01	0.38±0.09	0.47±0.06	0.57±0.03	0.82±0.11

Changes of soil pH and available P during cultivation

The changes of the distribution of soil pH and available P (Truog-P) in the soil profile in later growth period are shown in Figure 1. The soil pH was changed by the trenching procedure. Although no big change was observed for the pH in the control plot, subsoil pH tended to be lower in the subsoil mixed plot than in the control plot (Figure 2).

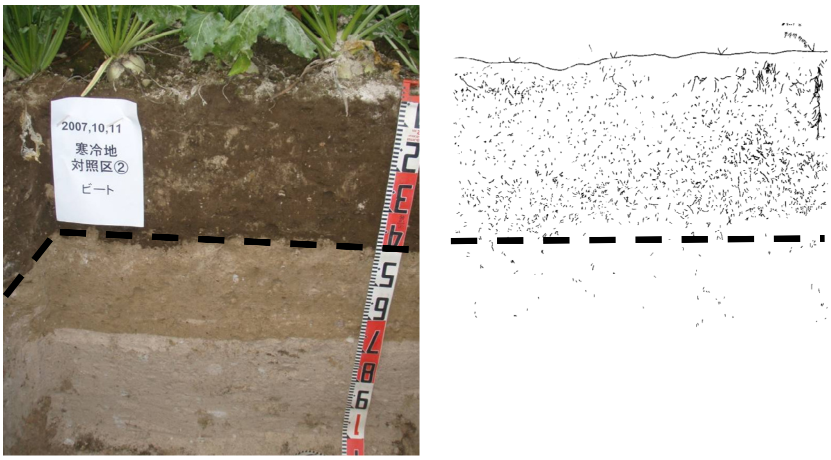


Figure 1. The soil profile morphology and the distribution of sugar beet fibrous roots. Dotted lines indicate the border of the A horizon and pyroclastic flow deposit layer (August 2007).

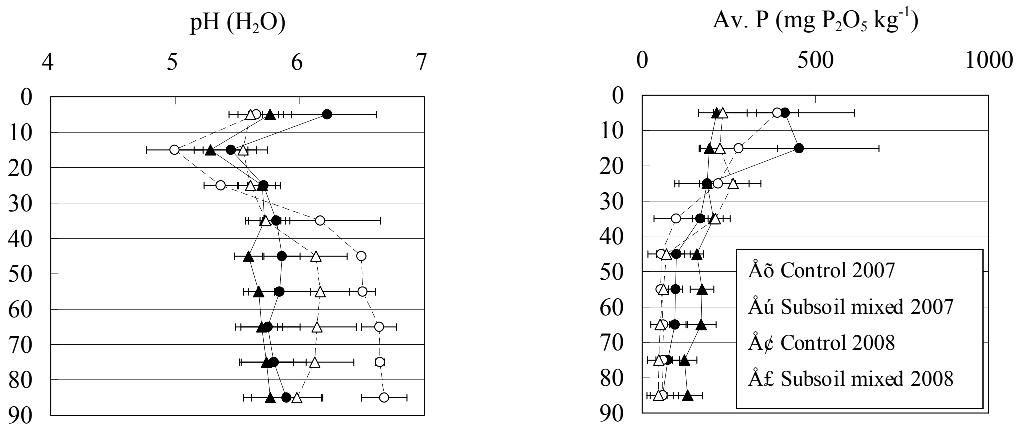


Figure 2. Changes of soil pH and available P distribution in soil profile in later growth period of sugar beet (October 17, 2007 and October 30, 2008). Horizontal and vertical axes indicate soil pH or available P and depth (cm). The values are the average of three replicated values and the error bars indicate the standard deviation.

This tendency was observed more clearly in 2008. The trenching procedure should decrease the subsoil pH by the mixing with low pH topsoil. Soil available P tended to be high in the surface soil for both plots due to the usual P fertilization. For the control plot, no obvious change was observed for Truog-P content during cultivation. However, in 2007, for the subsoil mixed plot, Truog-P content was low in the subsoil (40-90 cm) in June but increased later in the growth period. From July to October, the Truog-P content of subsoil was higher for the subsoil mixed plot than for the control plot. In 2008, Truog-P content was higher for subsoil mixed plot during the plant growth period. These tendencies were correlated to the pH change shown in Figure 1; soil Truog-P content tended to be high for the low pH condition. It is known that low pH increases the dissolution of apatite-P (Nanzyo *et al.* 1997), therefore, it was considered that the weathering of the apatite-P in the pyroclastic flow deposits was enhanced by the mixing with low pH topsoil.

Conclusion

From the results of our field experiment, we showed that using a trencher before planting increased the P uptake of sugar beet by promoting root development and apatite weathering. The apatite weathering should be enhanced by the contact of apatite mineral to topsoil with low pH and high active Al and Fe contents. We considered that the reaction with apatite-P and active Al and/or Fe should enhance apatite dissolution by reducing P concentration in soil solution. The contribution of apatite-P for increase of soil available P was shown by two years of field experiment. The apatite-P should be important P resource for agriculture. More detailed information about the changes of soil P forms will be discussed in the conference.

References

Blakemore LC, Searle PL, Daly BK (1981) Methods for Chemical Analysis of Soils. New Zealand Soil Bureau Scientific Report 10A. DSIR, New Zealand.

Chang SC, Jackson ML (1957) Fractionation of soil phosphorus. *Soil Sci*. **84**, 133-144.

Engelstad OP, Jugsujinda A, De Datta SK 1(974) Response by flooded rice to phosphate rocks varying in citrate solubility. *Soil Sci. Soc. Am. Proc*. **38**, 524-529.

Nakamaru MY, Nanzyo M, Yamasaki S (2000) Utilization of apatite in fresh volcanic ash by pigeon pea and chickpea. *Soil Sci. Plant Nutr*. **46**, 591-600.

Nakamaru, MY, Saito Y, Kobayashi H, Katougi S, Kuribara Y, Sato K, Tabuchi H, Hutaya S, Komatsu T (2008) Evaluation and utilization of the apatite-phosphorus in pyroclastic flow deposits in Abashiri district of eastern Hokkaido, *Japan. J. Agric. Sci., Tokyo Univ. Agric*. **53**, 200-207.

Nanzyo M (2002) Unique properties of volcanic ash soils. *Global Environmental Research*. **6**, 99-112.

Nanzyo M, Yamasaki S (1998) Phosphorus bearing mineral in fresh, andesite and rhyolite tephras in northern part of Japan. *Phosphorus Research Bulletin*. **8**, 95-100.

Nanzyo M, Takahashi T, Sato A, Shoji S, Yamada I (1997) Dilute acid-soluble phosphorus in fresh air bone tephras and fixation with an increase in active aluminum and iron. *Soil Sci. Plant Nutr*. **43**, 839-848.

Nanzyo M, Ebuchi Y, Kanno H (2003) Apatite in the pyroclastic flow deposit (1990-1995) of Unzen volcano, Japan, and its utilization by buckwheat. *Phosphorus Research Bulletin*. **16**, 1-10.

Parfitt RL (1978) Anion absorption by soils and soil materials. *Adv. Agron*. **30**, 1-50.

Rajan SSS, Watkinson JH, Sinclair AG (1996) Phosphate rocks for direct application to soils. *Adv. Agron*. **57**, 77-159.

Shoji S, Nanzyo M, Dahlgren RA (1993) Volcanic ash soils-Genesis, properties and utilization, Developments in Soil Science 21, pp. 171-176, Elsevier, Amsterdam.

Steven J, Kauwenbergh V (2008) Global Phosphate Rock Reserves and Phosphate Fertilizer Use. GSA-ASA-CSSA-SSSA joint annual meeting, Houston, TX.

Walker TW, Syers JK (1976) The fate of phosphorus during pedogenesis. *Geoderma* **15**, 1-19.

Determination of potassium supply power of some different soils

Roushani Ghorban Ali[A]

[A]Department of Soil and Water, Golestan Agricultural Research Center, Gorgan, Iran, Email gh_roshani@yahoo.com

Abstract
Neubauer seedling experiment was carried out for determining the K supplying power of different soils, in which seven soils from Iran, besides the three Indian soils were used. In this experiment, 100 seedlings of wheat were made to feed exhaustively on 100 grams of soil mixed with 100 grams of quartz sand for 20 days in plastic dishes. The total K uptake by wheat seedlings from soil was calculated from which the blank value was deducted to obtain the "root-soluble" K in soil. These values are designated as the Neubauer numbers, expressed as mg per 100 g of air-dry soil. The Neubauer limit value for wheat is 20 mg K per 100 g of dry soil and the soils which are having less value than the above is being considered to have poor K supplying capacity. It was observed that the Iranian soils are having more capacity to supply K than the Indian soils. Among the Indian soils, Alfisol, Vertisol, and Inceptisol with Neubauer numbers of 10.4, 8.6, and 2.8 are having highest, medium, and lowest potassium supply power, respectively.

Key Words
Potassium, suply power, Neubauer number and wheat.

Introduction
The potassium supplying power of eleven Ustochrepts of Delhi territory was determined by exhaustive cropping with Sudan grass (*Sorghum vulgare* var. sudanensis) in pots treated with 3 levels of potassium (0, 100, and 300 ppm). The exchangeable K content in the soil and the total potassium content in the plants after each crop were calculated. The residual exchangeable potassium showed a close correlation with the potassium supplying power of the soil (Deshmukh and Khera 1990).

The potassium supplying capacity of soils formed on three geological deposits of Nigeria was investigated by Loganathan *et al.* (1995). Soils formed on recent alluvial materials of the Meander Belt deposits (MBD) had mica and feldspars resulting in very high levels of total K and soils formed on the other two geological deposits (Sombreiro Warri deposits, SWD, and Coastal Plain Sands, CPS) had low levels of total K. Potassium uptake by maize induced a release of NE-K to the plant-available K pool. Potassium supply to plants from the NE-K pool for 3 successive maize crops in MBD, SWD and CPS soils were 303-435, 32-57 and 21-38 µg K /g soil, respectively. NE-K uptake, as a percentage of total K uptake, decreased with successive cropping in CPS soils and reached zero at the third cropping, while in MBD soils the percentage remained constant upto the third and last crop. In this respect, some SWD soils behaved similarly to MBD soils and others to CPS soils.

Surapaneni *et al.* (2002) evaluated a range of soil testing procedures for K for their ability to explain the variability between the 19 soils in both the uptake of total K from the soil and also the apparent uptake of K_{nex}. A new, simple soil testing procedure, involving extraction of soil K with dilute nitric acid (HNO_3- K), was found to be superior to a number of other published procedures, including estimates of exchangeable K (such as Quick Test K) and reserve K (involving multiple extractions with nitric acid), when correlated with dry matter yield and K uptake. An estimate of step K, calculated as the difference between HNO_3-K and Quick Test K, proved to be better than reserve K in explaining variations in K_{nex} uptake. The proposed HNO_3 extraction procedure is simple, cheap, and effective.

A model has been developed by Datta (2001) to simulate maximum K supplying capacity of a soil to a crop from different depths and the amounts of K released or fixed during cropping. The model is based on the equation of continuity with the assumption that nutrient flux from soil to root proceeds by mass flow and diffusion and influx into root follows Michaelis-Menten kinetics. Potassium fixation or release in soil has been simulated by incorporating a sink and source function, respectively, to the equation of continuity with the hypothesis that K release takes place in soil when K concentration goes below Release Threshold Level (*RTL*) and fixation takes place when K concentration goes above Fixation Threshold Level (*FTL*). This model has been validated and has been applied to simulate response towards fertilizer application at different available K. It has been shown that maximum response occurs at a particular value of available K which shifts towards higher value as *RTL* increases.

Methods
This experiment was done for determining the K supplying power of different soils, in which 12 soils from Iran, besides the 3 major Indian soils were used. In this technique, 100 seedlings of wheat were made to feed exhaustively on a limited quantity of soil (100 g) mixed with 100 g of quartz sand for 20 days in dishes of 11 cm diameter and 7 cm depth. A blank without any soil was also run. The total K uptake by seedlings from soil was calculated from which the blank value was deducted to obtain the "root-soluble" K in soil. These values are designated as the Neubauer numbers, expressed as mg per 100 g of air-dry soil.

Results
In this experiment, 100 seedlings of wheat were made to feed exhaustively on 100 grams of soil mixed with 100 grams of quartz sand for 20 days in plastic dishes. From the results of the Neubauer seedling experiment the Neubauer number (total potassium uptake by crop from 100g of a particular soil–total K uptake from control, that is, without soil) was calculated and is presented in Table 1. The Neubauer limit value for wheat is 20 mg K per 100 g of dry soil (Singh *et al.* 1999) and the soils which are having less value than the above is being considered to have poor K supplying capacity.

Table 1. The Neubauer number (mg K per 100 g soil) for different soils under study.

Soil order/ Location	Available K (mg/kg)	Dry matter yield (g) Shoot	Root	Total	K Uptake (mg./pot) Root	Shoot	Total	Neubauer Number
Inceptisol	60.8	1.39	1.42	2.81	3.70	6.03	9.73	**2.8**
Vertisol	158.0	1.47	1.37	2.84	5.00	10.5	15.5	**8.6**
Alfisol	50.3	1.64	1.62	3.26	6.85	10.5	17.4	**10.4**
Karkandeh	176.0	1.28	1.38	2.66	7.13	25.8	32.9	**26.0**
Golafra	52.9	1.59	1.59	3.18	5.10	23.9	29.0	**22.1**
Ilvar	76.6	1.68	1.70	3.38	6.63	27.6	34.3	**27.3**
Shamoshak	83.5	1.84	1.60	3.44	9.53	38.9	48.5	**41.5**
Kordkoy	98.1	1.79	1.55	3.34	8.70	41.5	50.2	**43.3**
Seejwal	255.0	1.68	1.61	3.29	11.2	38.5	49.8	**42.8**
Qara-ghashli	190.0	1.56	1.52	3.08	9.83	35.1	44.9	**38.0**
Blank	-	1.01	1.23	2.24	2.90	4.05	6.95	**-**

Conclusion
As evident from the data presented in Table 1, the capacity of Iranian soils to supply potassium is much more than Indian soils (at least double) and this is because of higher amount of solution K in Iranian soils as compared with Indian soils. Among the Indian soils, Alfisol, Vertisol, and Inceptisols with Neubauer numbers of 10.4, 8.6, and 2.8 are having highest, medium, and lowest potassium supply power, respectively.

References

Datta SC (2001) 'Annual reports of division of Soil Science and Agricultural Chemistry'. (Indian Agricultural Research Institute: New Delhi).

Deshmukh VN, Khera MS (1990) Potassium supplying power of some Ustochrepts under exhaustive cropping and varying external supply. *PKV Research Journal* **14,** 107-111.

Loganathan P, Dickson AA, Isirimah NO (1995) Potassium supplying capacity of soils formed on different geological deposits in the Niger Delta region of Nigeria. *Geoderma* **65,** 109-120.

Singh D, Chhonkar PK, Pandey RN (1999) 'Soil Plant Water Analysis: A Methods Manual'. (Indian Agricultural Research Institute: New Delhi, India).

Surapaneni A, Tillman RT, Kirkman JH, Gregg PEH, Roberts AHC (2002) Potassium-supplying power of selected Pallic soils of New Zealand 2. Soil testing procedures. *New Zealand Journal of Agricultural Research* **45,** 123–128.

Forms of soil acidity and the distribution of DTPA-extractable micronutrients in some soils of West Bengal (India)

Rajib Pati and **Dibyendu Mukhopadhyay**

Department of Soil Science & Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya, Pundibari, CoochBehar, West Bengal,India,736165, Email dibsm1@yahoo.co.in

Abstract

The distribution of the DTPA- (Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+}) in different pedons under *Terai* situations of West Bengal (India) was found to be governed by the forms of soil acidity. The pH and the organic carbon in soils had the major contributions towards the variation in extractable cations. The exchangeable Al^{3+} and total acidity contributed to the variation of extractable Fe^{2+}, Mn^{2+} and Cu^{2+}, while all forms of acidity except non-exchangeable form accounted for the availability of Zn^{2+} in soil solution. The different forms of acidity of the soils were quite comparable, although, the contribution of exchangeable acidity to the total potential acidity was low. The availability of nutrients varied with the soil depth and with different forms of acidity under the *Terai* situations of West Bengal. Significant correlations of extractable acidity and total potential acidity with the extractable Cu^{2+} and Zn^{2+} were observed for the given soils. The distribution of the forms of acidity with depth of soils varied on account of the changing accumulation of exchangeable bases at different depths in soils.

Key Words

Micronutrients, pedons, acidity

Introduction

Micronutrients in soils are important for plant growth and nutrition. The distribution of cationic micronutrients especially Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} in acid soils of India is sporadic. The different forms of acidity showed significant positive correlations with organic carbon and forms of Al^{3+} in soils but negative correlations with soil pH. Mondal *et al.* (2004) studied *Terai* soils of different land uses in India and found that exchange acidity (EA), total potential acidity (TPA), pH-dependent acidity (PDA) and total acidity (TA) had significant positive relationships with Al^{3+} and extractable-Al^{3+}. The non-exchangeable Al^{3+} and forms of soil acidity were positively and significantly correlated except for EA, indicating the dynamic equilibrium among different forms of aluminum and their role in soil acidity. The mean contents of iron and aluminium, extracted by various extracting reagents (Dolui and Maity, 2004), were in the order of dithionite>oxalate> pyrophosphate> KCl > ammonium acetate. The different forms of aluminium had significant contributions to the forms of soil acidity. Based on the above perspectives, the experiments were conducted with the following objectives; i) to determine the distribution of cationic micronutrients of some selected acid soils of *Terai* region of the Indian subcontinent and correlating the same with the important physicochemical properties of soils; ii) to characterize and compare different forms of acidity in soil layers and assess its influence on the availability of the extractable cationic micronutrients.

Methods

Eleven soil profiles representing three soil series (Binnaguri, Chunavati and Kharibari) of the order Entisol were exposed and soil samples were collected at different depths (0-90 cm.) in the districts of Darjeeling and Jalpaiguri under the *Terai* situation of West Bengal (India). The sampling areas were adjacent to tea gardens of different ages. The soil samples were analyzed for important physicochemical properties, following standard laboratory procedures. Micronutrient cations in soils were extracted with 0.005 (M) DTPA, containing 0.01 M $CaCl_2$, and 0.1 M TEA (Triethanol amine) buffered at pH 7.3 (Lindsay and Norvell, 1978). The extracts were analysed for Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+} by atomic absorption spectrophotometry. The exchangeable acidity of soils were measured following the method outlined by Sokolov (1939) and McLean (1965). The extractable acidity and total potential acidity were by the method of Baruah and Barthakur (1999). The non-exchangeable acidity was estimated indirectly as:

Non-exchangeable acidity = Extractable acidity – Exchange acidity

The pH-dependent acidity was estimated by the following equation

pH-dependent acidity = Total potential acidity – Exchangeable acidity.

Total soil acidity was measured by shaking the soil with 1N CH_3COOH (pH 8.2) for an hour (Kappen, 1934); the exchangeable-Al was determined following the principle as described by Baruah and Barthakur (1999). The statistical analysis was done with the standard software packages.

Results

There was variation of the exchangeable acidity (EA) of the soils at different depths (0-90 cm.) of the profiles under study. The contribution of EA to the total potential acidity (TPA) was low that corroborated the report of Dolui and Sarkar (2001). The mean value of exchangeable acidity in soils varied from 0.80-2.17 cmol(p^+) /kg. The form of non-exchangeable acidity varied from 0.17-0.80 cmol(p^+)/kg while that of exchangeable-Al^{3+} from 0.70-2.04 cmol(p^+)/kg. It was observed that the exchangeable aluminium had contribution towards the exchangeable acidity which was in agreement with the findings of Sharma *et al*. (1990), suggesting that the exchangeable acidity in soil was mainly due to monomeric Al^{+3} ions. Acidity occurring as variable charge (pH-dependent) as measured by the difference of total potential acidity (TPA) and exchangeable acidity (EA) varied from 28.32-59.29 cmol(p^+)/kg.It was observed that there was a decline in pH-dependent acidity in the sub - surface soils in most of the soils of the region. The other soils might have the participation of organic matter in the development of variable charge. The mean value of the total potential acidity of the soils varied from 29.43-61.32 cmol(p^+)/kg. It was apparent that the total potential acidity in most of the soils, decreased with the depth of soils (Figure 1). This might be due to the deposition of exchangeable bases with increasing soil depth. The higher values of the total potential acidity in some soils might be due to higher content of organic carbon which might have contributed to the total potential acidity through their functional groups like –COOH and phenolic –OH. The total acidity (TA) of the soils ranged from 2.85-4.66 cmol(p^+)/kg. The values of the total acidity were very low compared to those of TPA. This was related to the use of the extracting salts, i.e. $BaCl_2$ –TEA and CH_3COONa for this purpose. The extractable acidity varied from 0.97-2.71 cmol(p^+)/kg. This form of acidity possibly originated from the polyhydroxy molecule of Al^{3+} in soils.

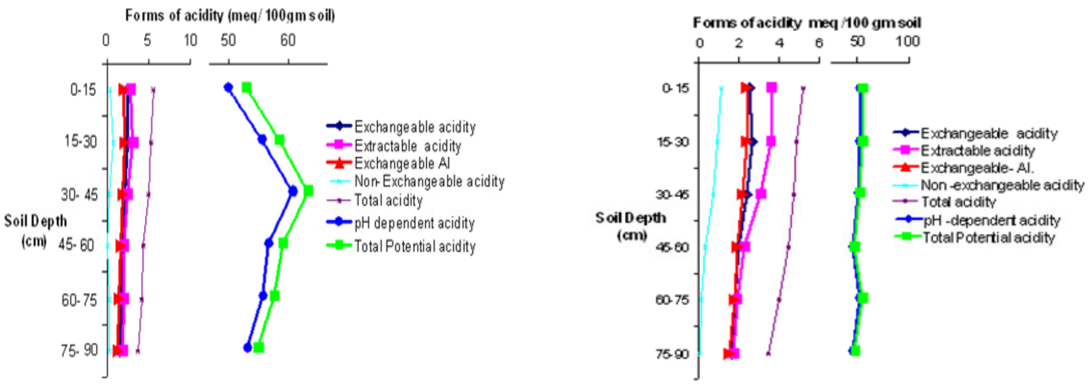
A gradual decrease of the Fe^{2+} content with soil depth (Figure 2) was observed. Considering the critical limit of 4.5 mg /kg soil (Anonymous, 1990), most of the soils were adequate in Fe^{2+} content in the surface soils.The DTPA-extractable Mn^{2+} content ranged from 0.40 to 6.14 mg /kg soil. A general trend of decrease of the Mn^{2+} content with the increase of the depth of the soils was observed. The DTPA-extractable Cu^{2+} content varied from 0.17 to 1.96 mg /kg, while that of extractable -Zn^{2+} varied from 0.28 to 0.91 mg /kg. A general trend of decrease of Zn^{2+} with depth was observed in the soils under study. Considering the critical limit of 0.60 mg /kg (Anonymous, 1990), the mean values of Zn^{2+} in some soils under study were low. A sharp decline in the extractable micronutrients (Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+}) in the sub-surface horizons indicated hardly any leaching to lower layers. It was observed that there was a general trend of lowering of the extractable cations with depth for the soil series under study. Initial sharp declines of the extractable iron up to a certain layers and subsequent gradual decrease to the lower zones for most of the soils were observed. The trend in distribution of extractable Cu^{2+} and Zn^{2+} in soil layers were similar, although, variations of the distribution of the extractable Mn^{2+} for some soils were observed.

A significant positive correlation (Table 1) was observed between the total acidity and extractable Fe^{2+} content (0.249*) of the soil. The exchangeable Al^{3+} and total acidity contributed 14.97% variation, although, inclusion of pH-dependent acidity could improve the variation to 18.43% on the availability of extractable-Fe^{2+}. Significant positive correlation of Mn^{+2} with exchangeable acidity (0.505**), extractable acidity (0.442**), and total acidity (0.560**) was observed (Table 1). The total acidity and pH-dependent acidity had the major contribution (5.56%) to extractable-Mn^{2+}. Significant positive correlations of extractable-Cu^{2+} with exchangeable acidity (0.371**), extractable acidity (0.324**), total acidity (0.340**) and total potential acidity (0.265*) were observed (Table 1). It was observed that the pH had a significant negative correlation (Table 1) with total acidity (-0.556**), exchangeable acidity (-0.607**), extractable acidity (-0.634**) and non-exchangeable acidity (-0.491**), suggesting that, these forms of acidity were responsible for lowering the pH of the soils. Exchangeable-Al contributed to 15.61% of the extractable-Cu^{2+} compared to the other factors (16.98%). Significant positive correlations of the extractable Zn^{2+} with exchangeable acidity (0.407**), extractable acidity (0.387**), total acidity (0.524**), pH-dependent acidity (0.337**) and total potential acidity (0.419**) were observed (Table 1). Total acidity had the major contribution (27.43%) to the variation of the extractable Zn^{2+}, although, both the exchangeable-Al and pH-dependent acidity could explained 32.21% of the variation in the DTPA-extractable Zn^{2+} of the soils.

Table 1. Correlations between the forms of acidity with cationic micronutrients and soil pH.

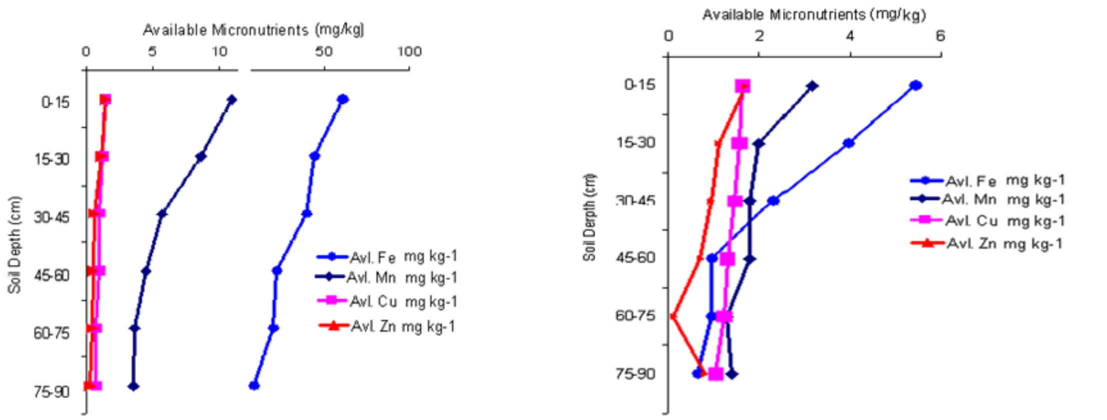
Types of acidity	Micronutrients				
	Fe^{2+}	Mn^{2+}	Cu^{2+}	Zn^{2+}	pH
Exchangeable acidity	0.023	0.505**	0.371**	0.407**	-0.607**
Extractable acidity	0.016	0.442**	0.324**	0.387**	-0.634**
Non-exchangeable acidity	0.001	0.206	0.146	0.239	-0.491**
Total acidity	0.249*	0.560**	0.340**	0.524**	-0.556**
pH-dependent acidity	0.225	0.048	0.199	0.337**	0.033
Total potential acidity	0.175	0.065	0.265*	0.419**	0.006

Significant at 0.05% level, ** Significant at 0.01% level



Binnaguri series **Chunavati series**

Figure 1. Distribution of forms of acidity with depth in soils.



Binnaguri series **Chunavati series**

Figure 2. Distribution of DTPA-extractable micronutrients with depth in soils

Conclusion

A general trend of decreasing extractable-micronutrients (Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+}) with depth in soils under *Terai* situations was apparent. The different forms of acidity governed the distribution of the extractable –micronutrients in soils. The effects of exchangeable acidity on the total potential acidity was low in the soils under study, although, the exchangeable Al^{3+} and total acidity had influences on the distribution of the DTPA-extractable micronutrients in soils.

References

Anonymous (1990) Annual Report, All India Coordinated Scheme of micro and secondary nutrients and pollutant elements in soils and plants. Indian Institute of Soil Science, Bhopal, pp-14.

Baruah TC, Barthakur HP (1999) *A Text book of Soil analysis*. pp-94-103. Vikas Publishing House Pvt. Ltd., New Delhi.

Das AN, Laskar BK, De GK, Debnath NC (1991) Nature of acidity of some acid soils of West Bengal. *Journal of the Indian Society of Soil Science* **39**, 246-251.

Deuis J, Freitas F (1984) In *Physical and Chemical methods of Soil and Water Analysis*. Oxford and IBH

Pub. Co., New Delhi, 51-106.

Dolui AK, Sarkar R (2001) Influence of nature of soil acidity on lime requirement of two Inceptisols and an Alfisol. *Journal of the Indian Society of Soil Science* **49**, 195-198.

Dolui AK, Maity B (2004) Nature of soil acidity in relation to different forms of iron and aluminium of some Alfisols of WestBengal. *Journal of the Indian Society of Soil Science* **52**, 415-420

Kappen G (1934) Popchvennaya Kislotnost, Selkhogiz, Moscow, Cf. *Journal of the Indian Society of Soil Science* **39**, 246.

Lindsay WL, Norvell WA (1978) Development of a DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society of America Journal* **42**, 421-428.

McLean EO (1965) Aluminum.In methods of soil analysis, part-II (C.A. Black, ed.) Chemical and microbiological properties of soils. American Society of Agronomy. Inc. Madison, Wisconsin, USA. pp.978-998.

Mondal GK, Pal SK, Roy A (2004) Effect of different forms of soil aluminium and acidity on P availability to wheat under different land uses in Terai soils of West Bengal. *Journal of the Indian Society of Soil Science* **52**, 286-288.

Sharma SP, Sharma, PK , Tripathi BR (1990) *Journal of the Indian Society of Soil Science* **38**, 189.

Sokolov AV (1939) Kimizastia Sots Zemledelia, 7, C. f. *Journal of the Indian Society of Soil Science* 246.

Identifying spatial variability of subsoil constraints using multiyear remote sensing and electromagnetic induction

Yash Dang[A,C], Matthew Pringle[B], Michael Schmidt[B], Ram Dalal[B] and Denis Orange[A]

[A]Department of Environment and Resource Management, Toowoomba, Qld.
[B]Department of Environment and Resource Management, Indooroopilly, Qld.
[C]Corresponding author. Email Yash.Dang@derm.qld.gov.au

Abstract
Subsoil constraints are important growth limiting factors in many soils of north-eastern Australia as they reduce the ability of roots to obtain water and nutrients. However, accurate information on the variability of subsoil constraints across the landscape is difficult to obtain. We developed an empirical-statistical model using historical wheat yield data, remotely sensed (Landsat) imagery and in-crop rainfall to estimate yield variability at sub-paddock scale to accurately identify areas suspected of subsoil constraints at farm scale. The yield predictions for 16 paddocks where wheat crops were grown during 2000-08 showed reasonably good agreement with farmer-reported yield (r^2 = 0.50). Analysis of the yield predictions showed 53% of the farm area exhibited consistently low yield, indicating the presence of at least one yield constraining factor. Soil samples averaged for low-yielding areas had substantially high concentrations of chloride in subsoil, high exchangeable sodium percent in the surface and subsoil and high nitrate nitrogen and volumetric moisture in the profile as compared to high-yielding areas. The results suggest that the paddocks or areas of paddocks exhibiting consistently low yields are an indicator of the presence of yield-limited factor/s. This offers the potential to map suspected areas of subsoil constraints.

Key Words
Subsoil constraints, Landsat, spatial variability, remote sensing.

Introduction
Salinity, sodicity, acidity and phytotoxic concentrations of chloride (Cl) in subsoils are major constraints to crop production in many soils of north-eastern Australia because they reduce the ability of crop roots to extract water and nutrients (Dang *et al.* 2006). Among subsoil constraints, subsoil Cl concentrations have a greater effect in reducing soil water extraction in the subsoil (Dang *et al.* 2008). Subsoil constraints vary both spatially across the landscape and vertically within soil profiles. Grid sampling to identify the distribution of possible subsoil constraints, both spatially across the landscape and within the soil profile, is time-consuming and expensive.

Crop yield mapping provides high-resolution estimates of spatially varying crop production; however, the adoption of yield mapping in Australia has varied (Jochinke *et al.* 2007), such that the detailed information is only patchy. Recent developments in sensing technologies have shown promise for quantifying soil and crop yield variations both within and between agricultural fields (Fisher *et al.* 2009). The potential advantages of remotely sensed images are: (i) the ability to bypass field measurements of yield; (ii) the ability to estimate yield at a range of spatial scales, thus eliminating sampling error within field variability; and, (iii) the availability of archived imagery thus enabling analysis of past growing seasons that may not have recorded yield (Lobell *et al.* 2007). Further, surrogate yield information may be generated from satellite images, allowing extrapolation to broader scales. Australia has more than 25 years of historical Landsat satellite data available. There is potential to increase the quantity and quality of spatial data needed to identify causes of spatial and temporal variability in cropping areas. We, therefore, attempted to develop an empirical-statistical model to predict yield variability at sub-paddock scale. This would determine consistently low yielding areas, and indicate the presence of a subsoil constraint.

Methods
We used historical mid-season normalised difference vegetation index (NDVI), generated from Landsat imagery to simulate wheat grain yield for a 3240-ha farm near Goondiwindi in southern Queensland, Australia (28° 19' S and 150° 30' E). In this area, wheat crops are generally sown in May. Anthesis is around mid-September, and crops are harvested during October. Long-term average annual rainfall for the area is 617 mm and average in-crop rainfall (May-October) is 225 mm. The climate of the region is semi-arid with

high potential evapotranspiration (1300-2200 mm per annum) (Webb *et al.* 1997). The common soil types of the farm are grey and brown Vertosols (Isbell 1996).

Site-specific yield data, available for 31 out of 55 wheat crops grown in 16 paddocks during 2000-2008, were accessed from the farmer, who collected yield data at harvest using AgLeader yield-monitoring equipment, linked to a differentially corrected GPS. Each field dataset was passed through several cleaning algorithms to remove erroneous yield associated with harvester dynamics, speed change, overlaps and turns. The clean yield data for each paddock and season was spatially interpolated with block kriging at the nodes of a 25-m grid, with 20-m blocks, using the Vesper software (Whelan *et al.* 2001). Cloud-free images of Landsat 5 TM (Thematic Mapper) and Landsat TM 7 ETM+ (Enhanced Thematic Mapper) satellite sensors were acquired close to anthesis. All images were geometrically and radiometrically corrected. The locations of each paddock boundary were identified on the satellite image, and the NDVI transformations were obtained for each crop where a wheat crop was grown during 2000-2008. For each node of the 25x25 m grain yield grid, the NDVI values were obtained using nearest neighbour interpolation.

A random selection of 5% of the data was used to develop the relationship between grain yield and NDVI and the in-crop rainfall before acquiring landsat (ICR-BL) image:

Grain yield = 1.1347 NDVI + 0.01389 ICR-BL; $r^2 = 0.72$, $P = 0.00001$, RMSE = 0.39 (1)

Grain yields were estimated in each year for each pixel using multiple linear regression equation between header yield and NDVI and validated with farmer-reported yield for wheat crops grown during 2000-2008. For estimating field-average surface and subsoil constraints, we performed survey using Geonics EM38® in vertical dipole mode to map apparent electrical conductivity (EC_a) levels. Soil cores to 1.5 m depth and separated in 8 depth intervals were taken at selected points as determined from EC_a surveys and analysed for physical and chemical properties (Dang *et al.* 2009). Soil pH, EC, Cl and NO_3-N were determined in 1:5 soil:water suspension. Electrical conductivity of saturation extracts (EC_{se}) was calculated from EC (1:5 soil:H_2O), Cl and clay content using the method of Shaw (1999). Cation exchange capacity (CEC) and exchangeable cations were determined using a 1M NH_4Cl (pH 8.5) extracting solution (Rayment and Higginson 1992). Prior to extraction, soluble salts were removed by pre-washing with 60% aqueous alcohol. The extracts were analysed for exchangeable cations on inductively coupled plasma-optical emission spectrometer. Exchangeable sodium percent (ESP) was calculated as ratio of exchangeable Na^+ to CEC. To identify areas suspected of subsoil constraints, the predicted yield images for each year were converted to percentiles, with 0 and 100% corresponding to minimum and maximum estimated yields. The proportion of each paddock that exhibited consistently low yields was compared with the proportion expected by chance at 80^{th} percentile (Lobell *et al.* 2007).

Results

Spatial variability of subsoil constraints

Across locations, average Cl concentrations, EC_{se}, and ESP increased with soil depth where as soil pH increased to 0.2 m and decreased at depth (Figure 1). Across locations at different depths, average Cl ranged from 49 to 1092 mg/kg to a depth of 1.5 m and EC_{se} ranged from 0.71 to 6.71 dS/m. Compared to Cl concentration, vertically averaged ECse was more spatially variable which was primarily due to the presence of gypsum at depth.

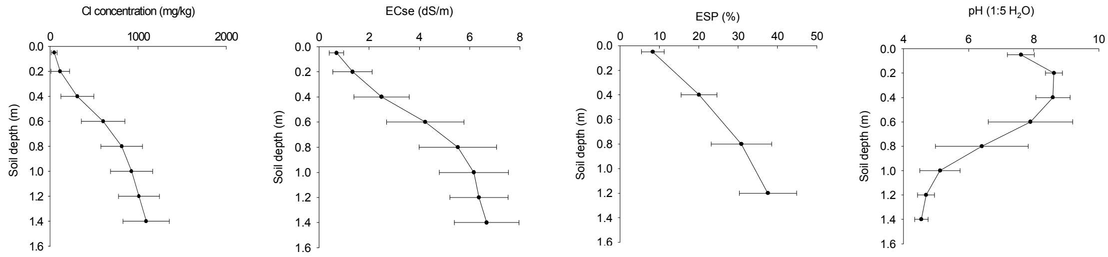


Figure 1. Average Cl concentration, electrical conductivity of saturated extract, exchangeable sodium percent, and soil pH with depth across whole farm. Error bars represent standard deviation.

Across locations, ESP ranged from 8 to 37% and soil pH ranged from 7.6 to 4.5 to 1.5 m and was more spatially variable than ESP at depth. Most of these soils were found to be saline (EC_{se} >4.0 dS/m) below 0.5

m depth, sodic (ESP ≥ 6%) below 0.1 m depth, and had potentially phytotoxic levels of Cl (> 600 mg/kg) below 0.5 m depth (Northcote and Skene 1972; Shaw, 1999; Dang *et al.* 2008).

Yield estimation

The Landsat-based yield estimates of 16 paddocks where wheat crops were grown during 2000-2008 showed reasonably good agreement with farmer-reported yield. Most of the values were near 1:1 line (Figure 2a). This relationship was further improved by using average yield estimate across all seasons-years and average farmer-reported yield for all seasons (Figure 2b) suggesting that use of single year of yield data or satellite image would not be enough to predict consistently low or high yielding areas of the paddock.

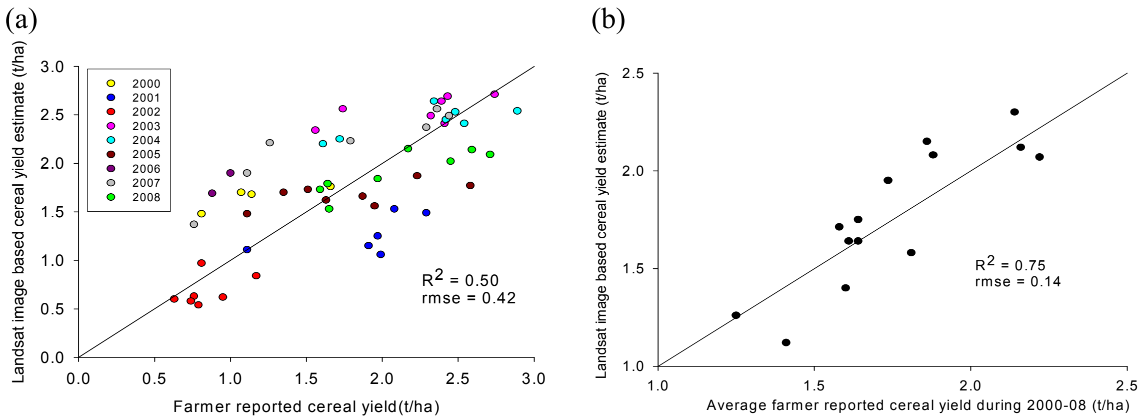


Figure 2. Comparison of Landsat-based wheat yields for 16 paddocks during 2000-08 with farmer-reported yields (a) for individual seasons, and (b) average of all seasons.

Identifying spatial variability of subsoil constraints

Using a threshold p = 80%, significantly more pixels never exceeded the threshold than would be expected by chance (Figure 3a), indicating the presence of a yield constraining factor. Fifty-three percent of the area never reached the 80th yield percentile (Figure 3b).

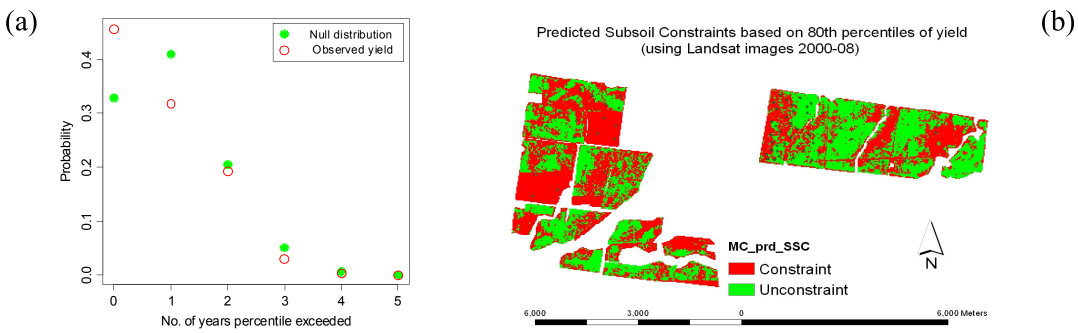


Figure 3. (a) Probability of pixel exceeding 80th percentile of yield, and (b) predicted subsoil constraints, for the entire farm.

Soil from unconstraint areas had substantially high concentrations of Cl in subsoil, high NO_3-N, volumetric moisture in the profile and high ESP in the surface soil as compared to constraint areas (Figure 4). High Cl in the subsoil restricts the ability of the roots to extract moisture and nutrients from subsoil, high ESP in surface soil results in soil crusting, water-logging, and poor germination. The presence of unused NO_3-N and moisture in the soil profile results in economic losses and environmental degradation (Dang *et al.* 2006).

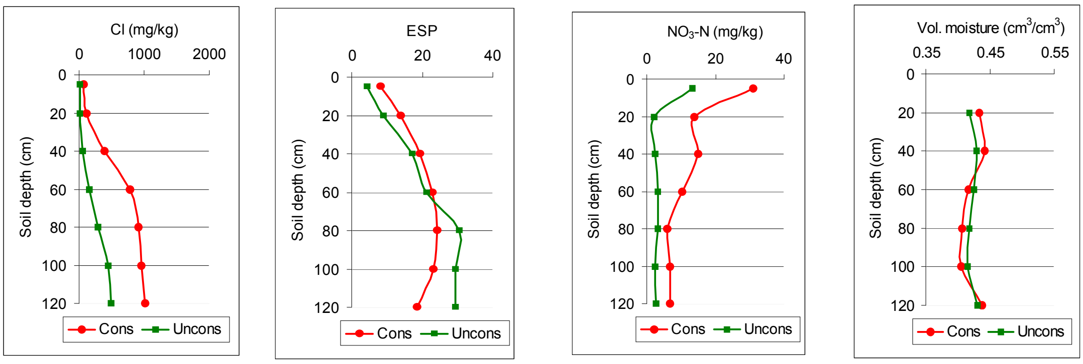


Figure 4. Comparison of Cl, ESP, NO_3-N, and volumetric moisture in constraint and unconstraint areas of the farm.

Conclusion

In cropped fields, sub-regions of low yield, consistent for several growing season, suggest the presence of a soil-related constraint. The techniques developed offer an opportunity to identify within-field spatial and temporal variability using satellite imagery as a surrogate measure of grain yield. The resulting information is directly useful for a farmer wanting to improve management spatially. It also helps stimulate further research hypotheses about the influence of soil variability on crop yield.

Acknowledgments

We wish to thank Peter and Jim Russell for providing yield data for their farms. We thank the Grains Research and Development Corporation for partial funding of this study.

References

Dang YP, Dalal RC Darr S, Biggs AJW, Moss J, Orange D (2009) Spatial variability of subsoil constraints in north-eastern Australia. In 'Proceedings of the Surveying & Spatial Sciences Institute Biennial International Conference, Adelaide'. (Eds B Ostendorf, P Baldock, D Bruce, M Burdett, P. Corcoran). pp. 1217-1229.

Dang YP, Dalal RC, Mayer DG, McDonald M, Routley R, Schwenke GD, Buck SR, Daniells IG, Singh DK, Manning W, Ferguson N (2008) High subsoil chloride reduces soil water extraction and crop yield from Vertosols. *Australian Journal of Agricultural Research* **59**, 321-330.

Dang YP, Dalal RC, Routley R, Schwenke GD, Daniells I (2006) Subsoil constraints to grain production in the cropping soils of the north-eastern region of Australia: an overview. *Australian Journal of Experimental Agriculture* **46**, 19-35.

Fisher PD, Abuzar M, Best F, Rab MA (2009) Advances in precision agriculture in south-eastern Australia, Part I: A methodology for the combined use of historical paddock yields and Normalised Difference Vegetation Index to simulate spatial variation in cereal yields. *Crop and Pasture Science* **60,** 844-858.

Isbell RF (1996). 'The Australian Soil Classification. Revised Edition'. (CSIRO: Collingwood, Australia).

Jochinke DC, Noonon BJ, Wachsmann NG, Norton RM (2007). The adoption of precision agriculture in an Australian broadacre cropping system-Challenges and Opportunities. *Field Crops Research* **104,** 68-76.

Lobell DB, Monasterio JI, Gurrola FC, Valenzuela L (2007). Identification of saline soils with multiyear remote sensing of crop yields. *Soil Science Society of America Journal* **71,** 777-783.

Northcote KH, Skene JKM (1972) 'Australian Soils with Saline and Sodic Properties'. (CSIRO: Collingwood, Australia).

Rayment GE, Higginson FR (1992). 'Australian laboratory handbook of soil and water chemical methods'. (Inkata Press: Melbourne)

Shaw RJ (1999) Soil salinity-electrical conductivity and chloride. In 'Soil Analysis-an Interpretation Manual'. (Eds KI Peverill, LA Sparrow, DJ Reuter) pp. 129-145. (CSIRO: Melbourne).

Webb AA, Grundy MJ, Powell B, Littleboy M (1997) The Australian sub-tropical cereal belt: soils, climate and agriculture. In 'Sustainable crop production in the sub-tropics'. (Eds AL Clarke, PB Wylie). pp. 8-26. (Queensland Department of Primary Industries: Brisbane).

Whelan BM, McBratney AB, Minasny B (2001) Vesper spatial prediction software for precision agriculture. In 'Proceeding 3rd European Conference on Precision Agriculture' (Eds G Grenier, S Blackmore) pp. 139-144. (Montpellier: France).

Isotopic technique for tracing both reduced and oxidised forms of sulphur in a fertiliser

Babasola Ajiboye[A], Samuel P. Stacey[A], Caroline Johnston[B] and Michael J. McLaughlin[A,B]

[A]School of Agriculture, Food and Wine, University of Adelaide, Adelaide, SA 5005 Australia, Email sola.ajiboye@adelaide.edu.au, samuel.stacey@adelaide.edu.au
[B]CSIRO Land and Water, Urrbrae SA 5064 Australia, Email caroline.johnston@csiro.au, mike.mclaughlin@csiro.au

Abstract
An isotopic technique was developed to trace both reduced and oxidised forms of sulphur in a fertiliser. Enriched ^{34}S (51.18 atom %) labelled-fertiliser was added to three different S responsive soils already labelled with a radioactive ^{35}S. The experimental design followed a randomised complete block design with 3 soils, two treatments (+S and –S) and 4 replicates. Canola plants were grown for 16 weeks under 20 °C/15 °C day/night temperatures. Harvested dry matter and seeds were analysed for total S by inductively coupled plasma optical emission spectrometry (ICP-OES) following a nitric acid digestion. Radioactivity of ^{35}S in the digests and atom % of ^{34}S in intact plant samples was measured on a liquid scintillation beta counter and a continuous flow isotope ratio mass spectrometry (CF-IRMS), respectively. From these measurements, the % of S derived from the fertiliser and specifically from ^{34}S° was calculated. There was a significant ($p < 0.05$) yield response to S in all three soils, with between 40 and 62% of the S in the plant coming from the added fertiliser. Over a 14 week period, < 10% of the elemental S in the fertiliser was taken up the plant. The combined stable and radioisotope technique has a potential for differentiating between plant uptake from sulfate-S and elemental S. This double labelling isotopic method can now be applied in the field to trace the uptake of SO_4-S and S°.

Key Words
Stable ^{34}S isotope, radioactive ^{35}S, CF-IRMS, atom %, specific activity.

Introduction
There is now an increasing recognition of S deficiency in agricultural soils, which has made the application of S-containing fertiliser a viable option. This is mainly due to the reduced atmospheric S deposition over the past few decades (Haneklaus *et al.* 2008). The increasing use of high analysis P fertiliser like mono- and di-ammonium phosphate (MAP and DAP), with low S content, over single super phosphate (SSP) might have also exacerbated this deficiency over the years (Blair 2008). The need to supply S continuously throughout the cropping season has led to different formulations of S-containing fertilisers; some of which have more than one form of S, mainly as quick release sulphate-S and slow release elemental S.

Isotopic techniques offer a superior quantitation of nutrient uptake from fertiliser than any other estimation of plant uptake. Isotopic technique has been used in the past to assess the efficiency of S fertiliser containing only one form of S (Karltun 1994; Di *et al.* 2000; IAEA 2001). In some of these studies, isotopic dilution was used. This involves the labelling of labile S and biologically incorporated S pools with a radioisotope ^{35}S and calculating the amount of plant S derived from the added S fertiliser indirectly from the ratio of labelled and unlabelled S in the plant. In other studies, the fertiliser was labelled with a stable ^{34}S and S uptake by plants measured by tracing (Zhao *et al.* 2001). Clearly, either of these two methods is limited in assessing the efficiency of different forms of S applied to the soil in the same fertiliser.

We therefore combined radio-isotopic dilution and stable isotopic tracing methods in order to distinguish S uptake from both oxidised and reduced S forms in fertilisers containing both these species. The labile and biologically incorporated S in the soil can be labelled with a radioisotope to quantify the amount of S taken up by the plant that came from the fertiliser. If one form of the S in the fertiliser can be labelled with a stable isotope and its uptake traced directly in the plant, the amount of S in the plant from each S form in the fertiliser can thereby be estimated.

The objective of the study was therefore to develop an isotopic dilution/tracing method to assess the efficiency of a fertiliser containing two forms of sulphur.

Methods

Labelling of fertiliser with enriched ^{34}S

The experimental fertiliser granules were made by grinding mono-ammonium phosphate (MAP), ammonium sulphate (AS), and highly enriched elemental S (99.8 atom %) in a "puck-mill". The particle size of the elemental S, as revealed by scanning electron microscopy ranged between 20 and 200µm. The mixture was then steam-granulated using a pan granulator. The S analysis of the resulting granules was as follows: total S = 10.95%, SO_4-S = 5.4%, S° = 5.5% and ^{34}S° = 51.18 atom %.

Pot experiments

Sulphur responsive soils were collected from 3 locations in South Australia. The soils range from slightly acid to neutral in reaction. Physicochemical characteristics of the soil are listed in Table 1. The soils were moistened to 10% of their maximum water holding capacity (MWHC) and uniformly labelled with carrier-free $^{35}SO_4^{2-}$ at the rate of 3 MBq/kg soil. The labelled soils were then allowed to incubate for 2 weeks to allow for an equilibration of the radioisotope with the labile and mineralisable S pool in the soils. A randomised complete block design (RCBD) was used with 3 soil types, 2 fertiliser treatments (+ S and – S), and 4 replicates, giving a total of 24 pots. Approximately 2 kg of each soil was packed into each pot to a bulk density of 1300 kg $m^{-3}$and wetted to 60% MWHC.

Table 1. Physicochemical characteristics of the soils.

	Texture	pH	Organic C %	NO_3-N	Sulfate-S	Colwell P	K	DTPA Zn	ECEC
				(-------------------	mg/kg	-------------------)			$cmol_c$/kg
Coonalpyn	Sandy Loam	5.4	0.7	12	4.2	45	84	0.89	2.2
Monarto	Loam	7	0.8	4	2.8	5	332	0.42	6.99
Wynarka	Sandy Loam	6.7	1	7	3.6	49	249	3.58	7.13
Approx. critical value					<7	<30	<40	<0.8	

The ^{34}S labelled fertiliser was added to the +S treatment at the rate equivalent to 15 kg S/ha (equivalent to the rate of 52 kg P/ha by the same fertiliser). The fertiliser was applied to simulate broadcast application with incorporation. Nitrogen, P, K and Zn were balanced in all the pots at an equivalent rate of 152, 25, 32, and 1 kg/ha, respectively. Four pre-germinated canola seeds (*Brassica napus* L. var ATR-Stubby) were transplanted into each pot and thinned to 2 plants per pot after 5 days. The plants were watered daily to replace transpirational losses and grown for 16 weeks under 20 °C/15 °C day/night temperatures. Upon harvesting, the above-ground part were divided into leaf+stem and pods and dried at 50° C for 1 week. The total yield (dry matter plus seed) was recorded for each pot.

Total plant S and specific radioactivity of ^{35}S

One gram of ground dry matter (shoot+leaves+pods) from each pot was digested in concentrated HNO_3, filtered and analysed for total S by ICP-OES. Two ml of the plant digest was thoroughly mixed with 10mL of the EcoScint A scintillant and the activity of the ^{35}S measured on a 1215 RackBeta II liquid scintillation counter (LSC) (LKB Wallac, Finland). In addition, 0.5 g of the seeds was digested in the same manner as the dry matter and analysed by ICP-OES and LSC.

Stable sulphur isotope ratio analysis

The plant samples are still undergoing further radioactive decay before they are sent for stable S isotope analysis. As a preliminary, plant samples from similar experiment on Wynarka soil without labelling of the soil with ^{35}S were analysed for stable S isotope ratio using a modification of the continuous flow isotope ratio mass spectrometry (CF-IRMS) method described by (Monaghan *et al.* 1999). Tin capsules containing reference or plant samples (≤ 8 mg) plus vanadium pentoxide (12 mg) catalyst were loaded into an automatic sampler, from where they were dropped, in sequence, into a furnace held at 1080 °C and combusted in a 25 ml pulse of pure oxygen. The combusted gases were then swept in a He stream (60 ml/min) over combustion catalysts (tungstic oxide/zirconium oxide) and through a reduction stage of high purity copper wires to produce SO_2, N_2, CO_2, and water. Water was removed using a Nafion™ membrane. Sulphur dioxide was resolved from N_2 and CO_2 on a packed Porapak™ QS GC column at a temperature of 32 °C .The excess CO_2 that preceded the SO_2 peak was 'valve-dumped' before entering the IRMS. Analysis was based on monitoring of *m/z* 48, 49, and 50 of SO^+ produced from disintegration of SO_2 in the ion source.

The reference material used for sulphur isotope analysis was an in-house standard IA-R036 (barium sulphate, $\delta^{34}S_{V\text{-}CDT}$ = +20.74 ‰). IA-R036, and two other in-house standards; IA-R025 (barium sulphate, $\delta^{34}S_{V\text{-}CDT}$ = +8.53 ‰) and IA-R026 (silver sulphide, $\delta^{34}S_{V\text{-}CDT}$ = +3.96 ‰) were used for calibration and correction of the ^{18}O contribution to the SO^+ ion beam. All these standards have been calibrated and traceable to NBS-127 (barium sulphate, $\delta^{34}S_{CDT}$ = +20.3 ‰) and IAEA-S-1 (silver sulphide, $\delta^{34}S_{V\text{-}CDT}$ = -0.3 ‰).

Calculations

The efficiency of the fertiliser (containing both elemental S and sulphate –S), expressed as % S derived from fertiliser (% Sdff), was calculated according to Equation 1.

$$\% \text{ Sdff } = [1 - (SA_{+S}/SA_{CONTROL})] \times 100 \quad [1]$$

where SA is the plant specific activity of ^{35}S (kBq mg^{-1} S), calculated as the ratio of ^{35}S radioactivity in plant (kBq/g) and total S concentration in the plant (mg/g).

The efficiency of the labelled elemental S was expressed as % S in the plant derived from elemental sulphur in the fertiliser (% SdfS°, which was calculated as a ratio of atom % of ^{34}S excess over the background in plant and that of the fertiliser, according to Equation 2. The % SdfS° was calculated for plants harvested after 14 weeks in Wynarka soil only.

$$\% \text{ SdfS}^{o} = (\text{atom } \% \ ^{34}S \text{ excess}_{PLANT}/\text{atom } \% \ ^{34}S \text{ excess}_{FERTILISER}) \times 100 \quad [2]$$

Statistical analysis of the total plant yield and % Sdff was performed using GenStat (Release 10.2) and differences among the treatments were identified using least significant difference (l.s.d) test at the 0.05 probability level.

Results and discussion

Plant response to sulphur

There was a significant yield response to S fertiliser in all the soils. The response was higher in the neutral soils than the slightly acid sandy soil (Figure 1). The S response was expected given the available S level in the soils, which was lower than the approximate critical level (Table 1). The measure of the efficiency of fertiliser added shows that between 40 and 62% of the plant S came from fertiliser (Figure 2). This suggests that approximately 38%, 50%, and 60% of the S in the plant came from the soil in the Coonalpyn, Monarto, and Wynarka soils, respectively. In the plant grown on Wynarka soil over a 14 week period, < 10% of the elemental S in the fertiliser was taken up by the plant. This indicates that most of the S in the plant that was derived from the fertiliser came from the sulphate-S in the fertiliser.

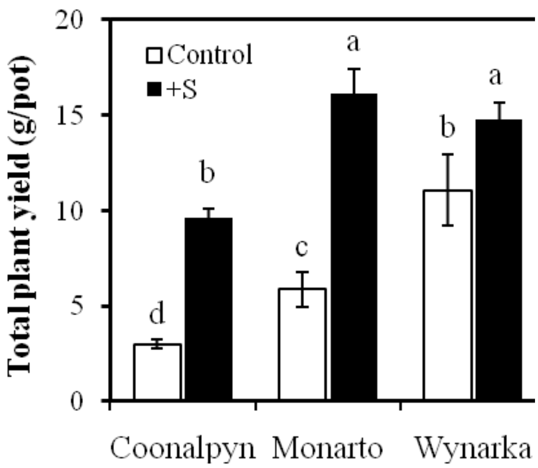


Figure 1. Canola yield response to S fertilisation. Mean with different letters are significantly different at 95% confidence level. l.s.d (5%) = 3.2g/pot

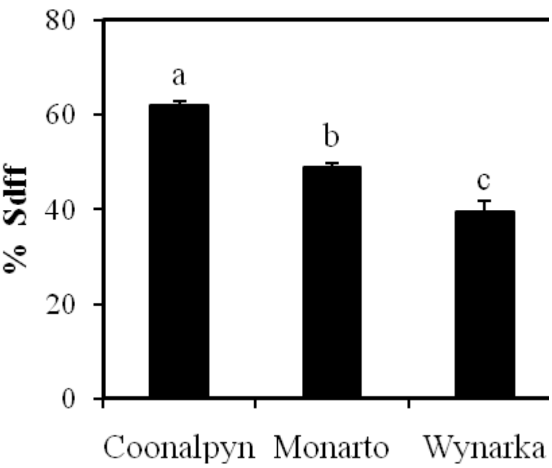


Figure 2. Proportion of plant S derived from fertiliser (%). Mean with different letters are significantly different at 95% confidence level. l.s.d (5%) = 8.5%.

By combining the enriched stable and radioisotope of S in a single experiment, there is a potential to quantify the amount of S taken up by the plant that originated from either the reduced or oxidized form of S in the fertiliser. Given the potential of the method presented in this paper to trace both SO_4-S and elemental S uptake by plants in a controlled environment, field plot experiments can now be carried out using the same procedure.

Acknowledgement
The authors would like to thank Mr. John Dighton, formerly with CSIRO, and Dr. Jeff Baldock for guidance on the stable S isotope ratio analysis and interpretation. Also, thanks to Ms. Deepika Setia and staff at Iso-Analytical Lab Cheshire, UK for technical assistance.

References

Blair G (2008) SSP: Single superphosphate, a scenario slowly passing. In 'Proceedings of the 14th Australian Agronomy Conference, Adelaide, South Australia'. (Ed. MJ Unkovich) (Australian Society of Agronomy): http://www.regional.org.au/au/asa/2008/concurrent/plant_nutrition/5950_blairg.htm

Di HJ, Cameron KC, McLaren RG (2000) Isotopic dilution method to determine the gross transformation rates of nitrogen, phosphorus, and sulfur in soil: a review of the theory, methodologies, and limitations. *Aust. J. Soil Res.* **38**, 213-230.

Haneklaus S, Bloem E, Schnug E (2008) History of S deficiency in crops. In 'Sulfur: a missing link between soils, crops and nutrition'. (Ed. J Jez), pp. 45-58. (ASA-CSSA-SSSA: Madison, WI)

IAEA (2001) Use of isotope and radiation methods in soil and water management and crop nutrition. IAEA-TCS-14. FAO/IAEA Vienna, Austria.

Karltun E (1994) The determination of adsorbed sulfate with isotopic dilution of sulfur (^{35}S) compared with calcium dihydrogen phosphate extraction . *Commun. Soil Plant Anal.* **25**, 207-214.

Monaghan J, Scrimgeour C, Stein W, Zhao F, Evans E (1999) Sulphur accumulation and redistribution in wheat (Triticum aestivum): A study using stable sulphur isotope ratios as a tracer system. *Plant Cell and Environment* **22**, 831-839.

Zhao FJ, Verkampen KCJ, Birdsey M, Blaje-Kalff MMA, McGrath SP (2001) Use of the enriched stable isotope ^{34}S to study sulfur uptake and distribution in wheat. *J. Plant Nutri.* **24**, 1551-1560.

Precision agriculture: challenges and opportunities in a flat world

R. Khosla

Department of Soil & Crop Sciences, Colorado State University, Fort Collins, CO 80523-1170. USA. Email: raj.khosla@colostate.edu

Abstract
Precision Agriculture has witnessed unprecedented growth in the last decade, especially in countries such as the United States, Germany and others. This paper will present the broad concept of precision agriculture with several examples of precision nutrient management from several countries. There, farmers and practitioners have overcome the challenges associated with precision nutrition management and converted them into opportunities by harnessing the global information and developing local precision techniques suitable for their region, operation and resources. With increasing global population and limited or decreasing arable land available for crop production the question arises "will we be able to overcome the future challenges and seize them as opportunities?" Precision agriculture management coupled with genetic improvements in crop traits will play a crucial role in meeting global demand for food, feed, fiber and fuel in the near and distant future.

Key Words
Precision agriculture, opportunities, challenges, global proliferation.

Introduction
Precision Agriculture has witnessed unprecedented growth in the last decade, especially in countries such as the United States, Germany and others. While the rest of the world has been relatively slow in embracing precision agricultural practices, the change is coming. From Australia to Zimbabwe, precision agriculture is growing across the globe. This is clearly evident by the number and diversity of manuscripts published in the area of precision agriculture in international journals and also by the variety of papers presented at the major international conferences on precision agriculture from different countries around the world. Publications and presentations may not be a scientific metric to account for the geographical spread but it indeed is a reflection of changing times and the proliferation of precision agricultural techniques and concept.

The advent of precision agriculture that occurred in the developed world about two decades ago involved application of advanced and innovative technologies. Precision agriculture in developed countries continued in that direction and today it is more sophisticated and complex than before. Interestingly, there are a number of definitions and concepts that can be found in literature pertaining to precision agriculture. The one that is most commonly cited and used by practitioners is the one that consist of several "R"s of Precision Agriculture. Robert *et al.* (1994) proposed three "R"s, the Right time, the Right amount and the Right place. Later, the International Plant Nutrition Institute added another "R" to that list, "the Right Source", and more recently, Khosla (2008) proposed an additional "R", the Right manner. For example, in precision nutrient management, "Right manner", refers to the method of placement of nutrient in the soil, (i.e.) broadcast versus banding, dribbling, injecting, etc. The "right manner" aspect may be not be very important for agriculture practiced in the developed world, however, it is of great importance for global precision agricultural practices.

The concept of "R"s does not mandate utilization of advanced technologies to practice precision agriculture. For example, it may take a suite of auto-pilots or high resolution guidance system on a 1000 hectare farm in the USA or Brazil to practice precision agriculture or it may take a group of skilled labors/farmers to practice precision planting on a 0.5 hectare field in a small farm in India or Asia. While the scale of farming is certainly contrasting in the two scenarios, both scenarios involved and implemented the "five R"s to identify and manage spatial and temporal variability, and hence would fall under precision agricultural practices.

Much of the recent research particularly in precision nutrient management has focused on the spatial and temporal aspects (i.e., right place and right time). Agricultural industry has been proactive in providing the innovative tools to realize the spatial and temporal management aspects of precision nutrient management. There is no doubt that significant progress has been made in managing nutrients more precisely across crop fields. However, there are still a number of challenges associated with precision nutrition management. For the ease of understanding, these are categorized on the basis of the four "R"s used in precision agriculture.

The right source

The right source of nutrient is not of grave concern since that has been identified and established for a long time. However, in the dynamic world of precision nutrient management, where the machine based decision is made in "real-time" it becomes imperative that we must realize the limiting nutrient(s) and adequately address the need with the correct source. For example, it is currently not feasible to differentiate the nutrient deficiency of iron versus nitrogen in maize (*Zea Mays*. L) crop field using sensing technology. Unfortunately, most or all of the precision nutrient management research has focused on the macro nutrients (the nitrogen, Phosphorus and Potassium). It is often assumed that other nutritional needs of the crop are met by uniform application. We need a suite of sensors that could identify the unique reflectance signature for various nutrient deficiencies in crop species.

The right place

Since inception of precision agriculture "the right place" aspect has received the most attention by scientists and practitioners. There are a number of sampling techniques and designs that allow us to characterize and quantify the scale and pattern of spatial variability in fields, such as grid soil sampling, site-specific management zones, smart sampling, soil electrical conductivity measurements, etc. However, we still need an economically feasible technique of quantifying the spatial variability in soil and crop properties at a scale that exists in the heterogeneous fields.

The right time

Availability of 'active remote-sensors" that can be mounted on high clearance fertilizer applicators has coupled the technology of "mapping variability in the crop canopy" and "variably applying fertilizer" simultaneously in "real-time". While the active sensors have been around for about 5 years, their adoption has been slow to come. The 14th annual survey of precision agricultural activities in the USA, indicate that the active sensor based fertilizer application ranks at the bottom of the list (Whipker and Akridge 2009). This could be attributed partially to the timing at which the commercially available active sensors can accurately quantify the variability in crop canopy. For example, research in Colorado, USA, has shown that active-sensors can accurately assess the spatial variability in crop nitrogen (N) needs at the maize growth stage of V12 (Ritchie, *et al.* 1992). Unfortunately, the majority or all the farmers in Colorado complete their N application for the growing season prior to that growth stage. Primarily because farmers are wary of potential delays in getting into the field due to rain, etc., which make them very hesitant in delaying in-season side-dress fertilizer applications. It will take a paradigm shift in changing the thought process of the farmers for them to adopt active-sensing based precision nutrient management or alternatively we need better sensing technology that could sense crop canopy early in the season to provide an estimation of crop nutrition needs, such that it coincide with farmer's "time" of applying nutrients (N) to the crop.

The right amount

After the advent of precision technologies, the right amount of nutrient to be applied across spatially variable fields was initially accomplished by utilizing existing nutrient recommendation algorithms developed by the research and academic institutions / Universities. However, it was soon realized that the traditional algorithm lack the robustness needed for the site-specific aspect of precision nutrient management. The new recommendation algorithms that are being developed are non-regional in approach and in some cases are unique to the site. This has created a new challenge to develop a database of multi-year field observations to create a reliable algorithm for precision nutrient recommendations that is accurate on a broader region. There is an opportunity for a technological innovation that would allow estimation of nutrient balance for each field that would aid in nutrient management and environmental sustainability. Irrespective of the challenges associated with Precision Agriculture and precision nutrient management in particular, the trajectory of precision agriculture, as witnessed over the past 20 years, is indeed correct. We will soon be venturing into the Precision Agriculture, version 2.0, in the future to meet the growing demand for food, feed, fiber, and fuel of the world.

The flat world

We are increasingly living in the "Flat World". If we were to expand our horizon across the globe, we will witness that it is indeed a flat world. In today's environment, an increase in fertilizer demand in Asia, impacts the local fertilizer prices in the USA. Likewise, a bumper crop produced in South America influences the commodity prices in Asia or Europe; or food scarcity in Haiti or Indonesia becomes a cause of concern for everyone. In a growing flat world, we are no longer insulated from external factors. There are clear signs that the global population and demand for high quality food is increasing. On the contrary, our arable land resource is decreasing and is competing with other factors such as population, bio-energy crops, and urbanization. What role precision agriculture would play to meet the increasing demand for food, feed, fiber, and fuel requirement of the world?

Precision agriculture is often misinterpreted by the developing world as complex technological intervention to agriculture, which is meant for large crop fields in the developed world. Precision agriculture and nutrient management however, can and will play an important role in lesser developed parts of the world. In a recent article in Economic Times (Dec 2009) by Dr. William Dar, Director General of ICRISAT (International Crop Research Institute for Semi-Arid Tropics), asserted that "*ICRISAT staff was able to increase grain yields of nutrient starved soils in Africa by carefully micro-dozing the nutrients to the crops*". This is an excellent example of precision nutrient management on small scale farms without large technological inputs. Like wise, Dobermann and Cassman (1996) fifteen years ago, proclaimed that precision nutrient management in the Rice-Wheat Cropping Systems in Asia, would provide another on-farm revolution. Wong *et al.* 2004 presented several case studies highlighting the methods in which farmers choose to improve their management of in-field variability. They concluded that precision agricultural research needs to focus on improving outcomes and not necessary the tools, to cater best for the needs of the farmers. Precision agriculture has the potential to contribute to increased production in diverse agricultural environments and conditions across the globe. Will we be able to overcome the future challenges and seize them as opportunities? Precision agriculture management coupled with genetic improvements in crop traits will play a crucial role in meeting global demand for food, feed, fiber and fuel in the near and distant future.

Conclusion

There are opportunities for adoption of precision agricultural techniques around the globe. The form of precision practices may be different from one place to another place, depending upon the creative mindset of farmers, practitioners, scientists and consultants local to the area of interest. This paper highlights the broad concept of precision agriculture with several examples of precision nutrient management practices from several countries where farmers and practitioners have overcome the challenges and converted them into opportunities by harnessing the global information and developing local precision techniques suitable for their region, operation and resources.

Reference

Ritchie SW, Hanway JJ, Benson GO (1992) How a corn plant develops. Iowa State University, Cooperative Extension Service, Ames, IA.

Dobermann A, Cassman KG (1996) Precision Nutrient Management in Intensive Irrigated Rice Systems – The Need for Another On-Farm Revolution *Better Crops and Plant Food* **10**(2), 20-25.

Khosla R (2008) The 9th International Conference on Precision Agriculture opening ceremony presentation. July 20-23rd, 2008.

Robert P, Rust R, Larson W (1994) Site-specific Management for Agricultural Systems, Proceedings of the 2nd International Conference on Precision Agriculture, 1994, Madison, WI. ASA/CSSA/SSSA.

Whipker LD, Akridge JT (2009) The 2009 Precision Agricultural Services: Dealership survey results. Developed by the Center for Food and Agricultural Business, Purdue University. www.agecon.purdue.edu/cab

Wong TFM, Stone PJ, Lyle G, Wittwer K (2004) PA for all - is it the Journey, Destination or Mode of Transport that's Most Important? In the CD-ROM proceedings of the 7th International Conference on Precision Agriculture, St. Paul., MN, USA.

Precision nitrogen fertilizer management of maize and cotton using crop sensors

Peter C. Scharf[A,F], Newell R. Kitchen[B], Kenneth A. Sudduth[B], John A. Lory[A], W. Gene Stevens[C], Luciane F. Oliveira[A], D. Kent Shannon[A], Harlan Palm[A], J. Glenn Davis[D], Earl D.Vories[E], David J. Dunn[C] and Andrea P. Jones[C]

[A]University of Missouri, Plant Sciences Division, Columbia, MO 65211.
[B]USDA-ARS, Columbia, Missouri 65211.
[C]University of Missouri, Plant Sciences Division, Portageville, MO 63873.
[D]USDA-NRCS, Columbia, Missouri, 65201.
[E]USDA-ARS, Portageville, MO 63873, U.S.A.
[F]Corresponding author. Email Scharfp@missouri.edu.

Abstract
Nitrogen fertilizer greatly increases crop yields but requires large amounts of energy to produce and has undesirable off-site effects when it escapes from agricultural systems. Precisely matching N fertilizer rates to crop needs maximizes benefits while reducing negative impacts. Soil N supply to crops is spatially variable, so spatial diagnosis is needed to apply optimal N rates. Crop reflectance sensors provide an accurate and spatially-intensive method for diagnosing and applying the correct N rate. We have developed calibrations relating optimal N rate to reflectance ratios for maize and cotton. These calibrations require that sensor reflectance measurements be expressed as a ratio with measurements from high-N areas that are matched in growth stage, genetics, and environment. We have used these calibrations in demonstrating sensor-guided N applications to maize and cotton producers. Side-by-side replicated comparisons of sensor-based variable-rate N and producer-chosen N rates for 53 maize fields resulted in N savings of 16 kg N/ha and a yield increase of 110 kg grain/ha. Results from our first four demonstrations in cotton fields should be available by the time of the congress. Drift of sensors during the course of a day has been an unexpected obstacle and requires frequent re-measurement of the high-N reference area.

Key Words
Spatial variability, diurnal variability, crop circle, greenseeker, cropscan.

Introduction
Nitrogen fertilizer is a crucial input for production of many of the world's major crops—maize, wheat, rice, cotton, potatoes, sorghum, and more. Smil (2001) estimates that 40% of the current human population would not be alive if the Haber-Bosch process for industrial fixation of nitrogen had not been invented.

Our research with maize suggests that it is common for economically optimal nitrogen rates to vary widely within a field (Figure 1) (Scharf *et al.* 2005; Mamo *et al.* 2003). Uniform application of the producer's normal N fertilizer rate to the field shown in Figure 1 would have resulted in both under- and over-application of N in various regions of this field. This conclusion agrees with most of the limited research on this subject to date. In our study, standard deviation for yield across landscapes was often much greater for unfertilized plots than for fertilized plots. This suggests that the soil's ability to supply N to the crop varies spatially. Coupled with a weak relationship between yield and optimal N rate, this suggests that soil N availability was the dominant factor controlling spatial variability in optimal N rate in our studies.

Characterizing soil N availability to the crop using soil tests has proven to be quite difficult, especially in humid regions. Scharf *et al.* (2006), in a network of 66 experiments over a large geographic area, found that chlorophyll meter readings (sensitive to leaf spectral properties) were a far better predictor of optimal N rate than were any of 16 soil mineral N measurements or 10 soil quick tests. Thus crop spectral properties appear to be one of the most promising methods for diagnosing optimal N rate. Reflectance sensors allow real-time measurement of crop spectral properties with nearly immediate translation into N rate decisions. Our objective was to develop calibrations relating sensor measurements to optimal N rates for maize and cotton, and to apply those calibrations in on-farm demonstrations of this technology.

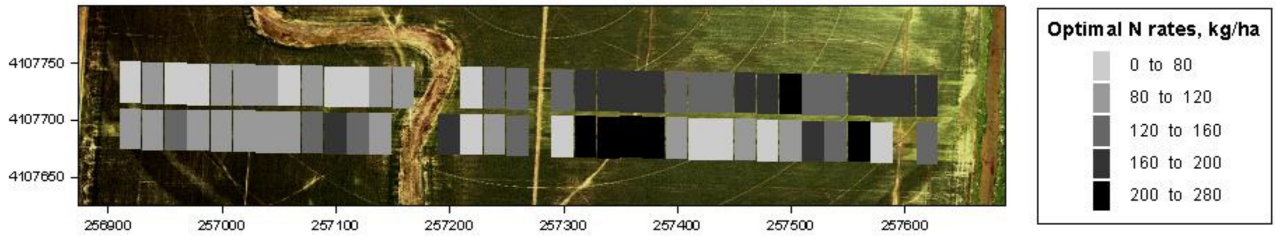


Figure 1. Spatial variation in economically optimal N fertilizer rate for maize. Each gray rectangle contained six N rate treatments (0, 55, 110, 165, 220, 275 kg N/ha) and yields associated with each N rate were measured. Yield response to N was modeled separately for each gray rectangle as a quadratic-plateau function. Economically optimal N rate was calculated from this function and prevailing prices for maize and N fertilizer at the time of the experiment. Economically optimal N rate for each experimental area is coded by the shade of gray. Optimal N rate in this field ranged from 50 to 230 kg N/ha, which was the smallest range among eight fields that we studied. Uniform application of the producer's normal N rate would have resulted in both under- and over-application of N in this field. Ticks are position coordinates (Universal Transverse Mercator) in meters.

Methods

Calibration of reflectance measurements against economically optimal N fertilizer rates was accomplished using a network of N rate response experiments for maize and for cotton. In each experiment, 40 or more plots were used to measure yield response to N rate, which was described using a quadratic-plateau model. Economically optimal N rates were calculated from these yield response functions using representative prices for N, maize grain, and cotton lint.

Reflectance was measured using one or more of three reflectance sensors:
Cropscan (Cropscan Inc., Rochester, MN, U.S.A.)
Crop Circle (Holland Scientific, Lincoln, NE, U.S.A)
Greenseeker (NTech Industries, Ukiah, CA, U.S.A)
The latter two sensors are termed 'active' based on having an internal pulsed light source.

Reflectance measurements were made at the stage of the main N application (V6 in maize—6 collared leaves and 30 cm height, early square in cotton—first flower buds appearing) in plots receiving 0 N at planting, low to moderate N rates at planting, and high N rates at planting. Later measurements were made on the same groups of treatments that had not received any in-season N applications.

Relative reflectance values were calculated for treatments receiving 0, low, or moderate N rates at planting by dividing their average reflectance by the average reflectance for high-N treatments.

Linear regression was used to relate economically optimal N rates to reflectance measurements. Each experiment produced 2 (maize) or 3 (cotton) data points for this regression, corresponding to the number of preplant N rates for which independent optimal in-season N rates were calculated and for which independent sensor measurements were collected.

The resulting calibration equations were used to control variable-rate N applications in field-scale demonstrations using fertilizer applicators owned by producers or agricultural service providers. At least three replications were used in each field to compare variable-rate N applications (controlled by sensors) to uniform applications at a rate chosen by the cooperating producer. Yield monitors were used to collect yield data for both crops, and N rate, yield, and profitability were calculated for both treatments.

Results

A wide range of optimal N rates was observed for both crops. This facilitated the development of good calibrations between optimal N rate and sensor measurements. Visible/NIR reflectance, relative to the same measurement from high-N plots, successfully predicted optimal N rate in both crops and all sensors. In maize, useful predictions could be made as early as the V6 stage (Figure 2), which was the earliest stage studied. In cotton, relationships at the early square stage (the earliest stage studied) mostly had r^2 values of 0.3 or less, but useful relationships were found at the mid-square and early flower growth stages (Figure 3).

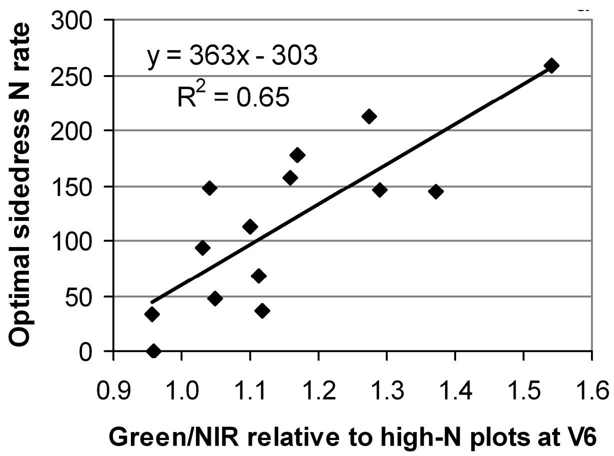


Figure 2. Optimal N rate for maize was reasonably well related to green/NIR reflectance (relative to the high-N treatment) measured with the Cropscan radiometer at the V6 stage. The equation shown was used in translating sensor measurments to N rates in subsequent field-scale demonstrations of sensor-guided N application.

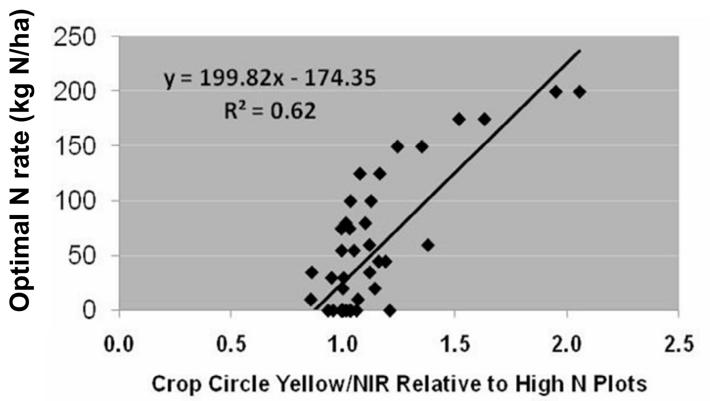


Figure 3. Optimal N rate for cotton was reasonably well related to yellow/NIR reflectance (relative to the high-N treatment) measured with the Crop Circle radiometer at mid-square/early flower stages. The equation shown was used in translating sensor measurments to N rates in subsequent field-scale demonstrations of sensor-guided N application.

In field-scale demonstrations of sensor-guided variable-rate N for maize using the calibrations reported above, sensor-based rates out-performed N rates chosen by cooperating producers (applied at the same time). For the period 2004-2007, the economic advantage of sensor-based management was due to the ability to reduce N rate, relative to the producer rate, without suffering any yield penalty (Table 1). This was average behavior, while in fact the use of sensors decreased yield in some demonstrations and increased yield in others, with a net effect of zero.

In 2008, with an unusually wet spring, much background soil nitrate and ammonium were lost. More N was applied using sensors than using the rate chosen by the producers. This turned out to be a correct decision, increasing yield and profit relative to producer-chosen rates (Table 1).

Similar field-scale demonstrations have been carried out in cotton in 2009. We should be able to report those results at the congress.

Table 1. Average outcome of sensor-based N management in 53 field-scale demonstrations in maize. Effect on profit is based only on yield and N use. Cost of implementation is difficult to calculate and is not included.

Period	# Fields	Effect of sensor management[A] on:		
		Yield	N rate	Profit
		Mg/ha	Kg N/ha	$/ha
2004-2007	41	0	-27	+30
2008	12	+0.6	+18	+72

[A]Relative to N rates chosen by cooperating producers.

We have found that sensor measurements drift during the day when mounted in a stationary position over the same plant all day long. This is true for both maize and cotton. One factor in this drift can be leaf wetness, as demonstrated by spraying water on leaves while taking measurements. However, a great deal of the variation that we have observed cannot be attributed to this source and we do not know the source. Greenseeker sensors repeatably have low visible/NIR values in morning and evening, with higher values at mid-day, and are the most variable of the three sensors we have studied (Figure 4).

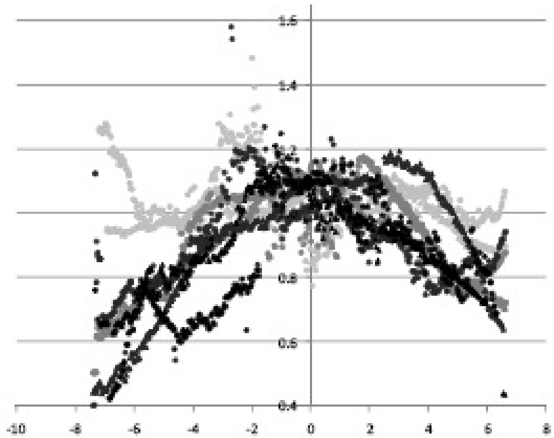


Figure 4. Normalized visible/NIR for the Greenseeker sensor as a function of time (0 = solar noon, and visible/NIR value at solar noon was defined as 1.0 in normalizing the day's data). Data were collected on eight separate days from a stationary position above a single cotton plant.

Conclusions

- We were able to calibrate reflectance sensors to predict optimal N fertilizer rates for both maize and cotton.
- Using these calibrations to control N rate in field scale demonstrations produced at least some success in diagnosing and responding appropriately to differences in soil N supply to the crop. Sensor-based N management used less N and produced more yield and profit than producer-chosen rates in 53 demonstration fields.
- Additional work to eliminate or compensate for sensor drift will be important to successful deployment for wide-scale nitrogen fertilizer management.

References

Mamo M., Malzer GL, Mulla DJ, Huggins DR, Strock J (2003) Spatial and temporal variation in economically optimum nitrogen rate for corn. *Agron. J.* **95,** 958–964.

Scharf PC, Brouder SM, Hoeft RG (2006) Chlorophyll meter readings can predict nitrogen need and yield response of corn in the north-central USA. *Agron. J.* **98,** 655–665.

Scharf PC, Kitchen NR, Sudduth KA, Davis JG, Hubbard VC, Lory JA (2005) Field-scale variability in optimal nitrogen fertilizer rate for corn. *Agron. J.* **97,** 452–461.

Smil V (2001) 'Enriching the Earth'. (MIT Press: Cambridge, MA).

Relationship between multi-spectral data and sugarcane crop yield

Fernando Benvenuti[A] and **Mara Weill**[B]

[A]Cosan Group, Piracicaba, SP, Brazil, Email Fernando.Benvenuti@cosan.com.br
[B]College of Agricultural Engineering, State University of Campinas, Campinas, SP, Brazil, Email mweill@agr.unicamp.br

Abstract
In Sao Paulo State, the extent of agricultural land under sugarcane production encompasses 3.2 million ha which produce more than 300 million Mg/y. In 2006, this corresponded to 60% of the national yield. Due to these huge numbers reliable yield estimations are vital for adequate crop production planning and monitoring at production units. The purpose of this work was to assess the relationship between spectral data and sugarcane yield in a commercial production area in Sao Paulo State to forecast harvest. Three Landsat 7/ ETM+ images were used to extract spectral variables from sugarcane plantations, two of them during the period of maximum vegetative crop growth and the third at the beginning of the maturation stage. Before analyses, the images were processed to perform geometric and radiometric restorations. Three spectral variables were extracted: reflectance of the band 4 (0.76-0.90um), NDVI and GVI indices. Simple linear regression analyses were performed between sugarcane yield (dependent variable) and spectral variables (independent variables). The average values of NDVI, GVI, and reflectance of band 4 declined with time. The temporal differences were significant for GVI index and reflectance of band 4. However, they were not significant for the NDVI index, which is indicative of a less sensitivity of this index to detect multi-temporal differences in sugarcane spectral response during its lifecycle.

Key Words
Yield prediction, vegetation indices, multi-spectral data, remote sensing.

Introduction
In Brazil, sugarcane plantations cover more than 6.2 millions of hectares (CONAB). From this total, 3.2 millions correspond to the planted area in Sao Paulo State, where a hundred of productive units produce up to 300 million Mg/y that represent almost 60% of the national sugarcane yield. Given these huge numbers, methods to forecast harvest are vital not only for adequate monitoring of the production units but also to anticipate the negotiation of sugarcane industrial products, sugar and ethanol. In this context, multi-temporal remote sensing data makes possible monitoring the crop growth during its lifecycle, and also to get anticipated information to forecast harvest. This is due to the fact that healthy canopies of green vegetation have a very distinct interaction with energy in the visible and near-infrared regions of the electromagnetic spectrum that can be detected and quantitatively assessed (Thiam and Eastman 1999). Spectral vegetation indices are models designed to provide a quantitative assessment of green vegetation biomass. Miura *et al.* (2001) had mentioned their application to monitor the vigor of the vegetation cover on global and regional scales. Other authors had already mentioned the correlation between spectral vegetation indices and bio-physical parameters of the vegetation, including leaf area index, biomass, yield, leaf photosynthetic activity, photosynthetic active absorbed radiation (PAR), fraction of photosynthetic active radiation absorbed by the plantation (*f*APAR), and green cover percentage (Huete 1988; Epiphanio and Huete 1994; Elvidge and Chen 1995). In Brazil, the relationship between spectral response of sugarcane and yield was studied by Fortes (2003), Machado (2003), and Simões (2005). The purpose of this work was to assess the relationship between spectral data and sugarcane yield in a commercial area in Sao Paulo State.

Methods
Study area
The studied area encompassed 15 plots occupying 150ha cultivated with a medium maturation sugarcane variety. General topography is gentle (0.05m/m), with increasing slopes until 0.13m/m at the lower part of the hillsides. Main soil types occurring in the area include Typic Hapludox (Red Yellow Latosols medium textured) and Typic Quartzipsamments, both distrofic or with base saturation under 50%. Sugarcane yield records per plot (n=15) for the agricultural year 2002/03 were extracted from the agricultural data base available at the production unit.

Remote sensing data
Three Landsat 7/ ETM+ images, scene 220-076, were used to extract spectral variables from sugarcane plantations in the study area. The first two (dated of Jan 08 and Feb 25, 2003) were chosen to represent the period of maximum vegetative crop growth, and the third (dated of May 16, 2003) to represent the beginning of the maturation stage. Prior to analyses, geometric and radiometric restorations were performed. The atmospheric interferences were corrected employing the software Scoradis (Zullo Junior, 1994), using entry atmospheric parameters extracted from MODIS (*Moderate Resolution Imaging Spectroradiometer)* images, designed by *Level 2 Aerosol over Land and Ocean Product* (MOD04_L2). Three spectral variables were extracted from the images: the reflectance of band 4 (b4, 0.76 – 0.90 µm), corresponding to near-infrared (NIR); the Normalized Difference Vegetation Index (NDVI), introduced by Rouse *et al.* (1974) and calculated by equation 1, and, the Green Vegetation Index (GVI) of the Tasselled Cap, originally described by Kauth and Thomas (1976), and calculated by equation 2 as described by Crist (1985). The image processing and analyses were performed in a GIS environment.

NDVI = (NIR-RED)/ (NIR+RED) (1)
Where: NIR (near infrared, 0.76-0.90µm) and RED (b3, 0.60-0.70µm) of Landsat 7/ ETM+sensor.

GVI = - 0.1603*b1 – 0.2819*b2 – 0.4934*b3 + 0.7940*b4 – 0.0002*b5 – 0.1446*b7 (2)
Where: b1(blue, 0,45-0,52µm), b2 (green, 0,52-0,60µm), b3 (red, 0,60-0,70µm), b4 (NIR, 0,76-0,90µm), b5 (MIR, 1,55-1,75µm), and b7 (MIR, 2,08-2,35µm) of Landsat 7/ ETM+sensor.

Statistical analysis
The relationship between sugarcane yield (dependent variable) and spectral variables (independent variables) was assessed by simple linear regression analyses, employing the software Statistica 6.0. The average value per plot of each spectral variable (b4, NDVI, and GVI) was calculated. In this operation, to exclude the influence of the soil reflectance at the corridors, only the values of the pixels inside each plot were computed (only sugarcane). Then, for each plot (n=15) the values of the spectral variables were correlated with the correspondent sugarcane yield record. Before performing the regression analyses, the normality of yield and spectral data distributions was tested.

Results
Temporal variation of spectral data has shown that average values of NDVI, GVI, and reflectance of band 4 declined with time (Figure 1). For GVI and reflectance of b4, values in January were bigger and statistically different than in February and in May. For NDVI, no differences were found among average values for the three dates, showing the lower sensitivity of this index to detect multi-temporal differences on sugarcane spectral response during its lifecycle. About this point, Moreira (2000) had stated that after certain degree of crop development, NDVI values became invariable and insensitive to increases in green biomass. From the results of Table 1, it can be observed that independent of the crop age, the better performance was for the GVI index. The NDVI index was less efficient to explain sugarcane yield variation in the study area. Despite the fact that both indices, GVI and NDVI, are based on the contrast between the spectral responses of the green biomass in visible and in near infra-red regions (Crist and Cicone 1984), the GVI index has the advantage of considering not only the bands 3 (red) and 4 (near infra-red), like the NDVI index, but also by computing the responses in bands 1 (blue) and 2 (green), which incorporates the influence of photosynthetic pigments present in leaves, and in bands 5 and 7 (medium infra-red), both sensitive to the water content in leaves. The results indicate that the relationship between sugarcane yield data and spectral variables was influenced by crop age and phenological stage. For GVI index and reflectance of band 4, the best fit was found by employing the Feb 25, 2003 Landsat image, practically at the middle of the annual lifecycle of the crop, or when sugarcane plants had an age of 6.3 months (190 days). The best simple linear regression model is represented by equation 3. This model could explain 79% of the observed variation on sugar cane yield in the study area as a function of the GVI value at Feb 25, 2003. The model is significant with 95% confidence ($p < 0.0001$) and the residues show normal distribution according to the *Shapiro-Wilk* test (p-value= 0,597).

Sugarcane yield (Mg/ha) = -23.6820 + 5.9434 GVI_Feb 25 (R^2 =0.79) (3)

For practical application, the model must be validated with supplementary analyses.

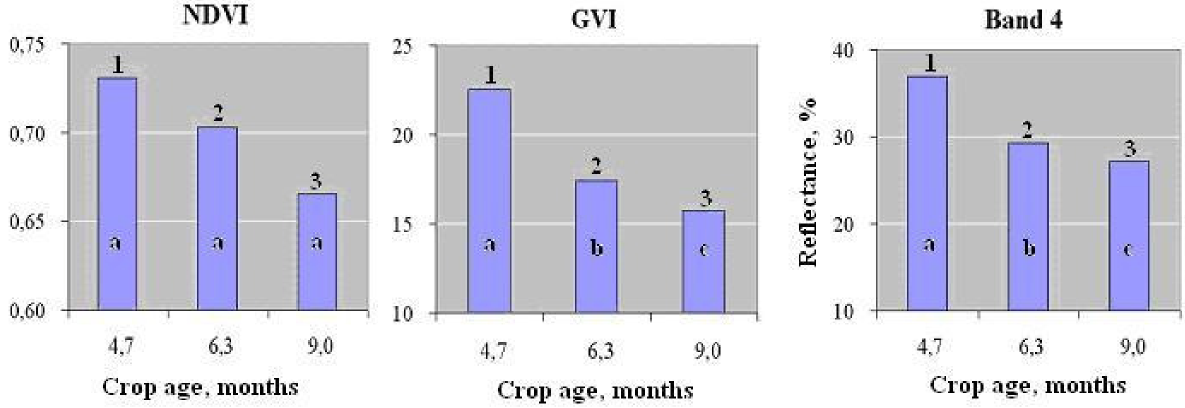


Figure 1. Average values of spectral variables NDVI, GVI, and reflectance of b4 calculated for three dates during sugarcane lifecycle (1- Jan 8, 2- Feb 25, 3- May 16; for each image n=15). For the same spectral variable, average value (represented by bar) assigned with the same case letter don't present statistical difference at the 0,05 confidence level by Tukey test.

Table 1. Results for simple linear regression analysis between sugarcane yield and spectral variables.

Image date	Crop age (months)	Number of observations	NDVI		GVI		Band 4	
		n	R^2	*p-value*	R^2	*p-value*	R^2	*p-value*
Jan 08, 2003	4.7	15	0.65	0.0003	0.68	0.0001	0.34	0.0229
Feb 25, 2003	6.3	15	0.61	0.0005	0.79	<0.0001	0.76	<0.0001
Mai 05, 2003	9.0	15	0.62	0.0005	0.74	<0.0001	0.71	<0.000

Conclusion

Spectral data extracted from sugarcane plantations at the middle of surcarcane annual lifecycle has shown a direct and strong relationship with the final crop yield observed in the study area. The use of spectral variables seems to be a good alternative procedure for obtaining valuable information to enable forecast of the harvest.

References

Benvenuti FA (2005) Relação de índices espectrais de vegetação com a produtividade da cana-de-açúcar e atributos edáficos. Dissertação (Mestrado em Engenharia Agrícola), Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas.

Crist EPA (1985) TM tasseled cap equivalent transformation for reflectance factor data. *Remote Sensing of Environment* **17**, 301-306.

Crist EP, Cicone CC (1984) A Physically-Based Transformation of Thematic Mapper data – The TM Tasseled Cap. IEEE Transactions on Geosciences and Remote Sensing, v.GE-22, n.3, may.

Elvidge CD; CHEN Z (1995) Comparison of broad-band and narrow-band red and near-infrared vegetation indices. *Remote Sensing of Environment* 54, 38-48.

Epiphanio JCN; Huete AR (1994) Influence of sun-view geometries on the relationships among vegetation indices, LAI, and absorbed PAR. In 'International Geoscience and Remote Sensing Symposium (IGARSS'94). Surface and Atmospheric Remote Sensing, Pasadena'. *Proceedings. Piscataway: IEEE* **3**, 1455-1457.Fortes C. (2003) Discriminação varietal e estimativa de produtividade agroindustrial de cana-de-açúcar pelo sensor orbital ETM+/LANDSAT7. 131p. Dissertação (Mestrado em Agronomia), Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba.

Huete AR (1988) A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment* **25**, 295-309.

Kauth RJ; Thomas GS The tasseled cap – A graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. In 'Proc. The Symposium on Machine Processing of Remotely Sensed Data, Purdue University, West Lafayette, Indiana' pp. 41-50, 1976.

Machado HM (2003) Determinação da biomassa da cana-de-açúcar considerando a variação espacial de dados espectrais do satélite Landsat 7 – ETM+. Dissertação (Mestrado em Engenharia Agrícola), Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas.

Moreira RC (200) Influência do posicionamento e da largura de bandas de sensores remotos e dos efeitos atmosféricos na determinação de índices de vegetação. Dissertação (Mestrado em Sensoriamento Remoto) Instituto de Pesquisas Espaciais, São José dos Campos-SP (INPE-7528-TDI/735).

Miura T, Huete AR, Yoshioka H, Holben BN (2001) An error and sensitivity analysis of atmospheric resistant vegetation indices derived from dark target-based atmospheric correction. *Remote Sensing of Environment* **78**, 284-298.

Simões MS, Rocha, JV, Lamparelli RAC (2005) Spectral variables, growth analysis and yield of sugarcane. *Sci. agric. (Piracicaba, Braz.)*.**62**, 199-207.

Thiam A, Eastman JR (1999) 'Vegetation Indices. In: Guide to GIS and Image Processing'. V.2. Idrisi 32. Clark Labs. (Clark University: Worcester, MA).

Zullo JJ (1994) Correção atmosférica de imagens de satélite e aplicações. 189p. Tese (Doutorado em Engenharia Elétrica), Faculdade de Engenharia Elétrica, Universidade Estadual de Campinas.

Relationship between spectral sugarcane data and local variation of soil attributes

Mara Weill[A] and Fernando Benvenuti[B]

[A]College of Agricultural Engineering, State University of Campinas, Campinas, SP, Brazil, Email mweill@agr.unicamp.br
[B]Cosan Group, Piracicaba, SP, Brazil, Email Fernando.Benvenuti@cosan.com.br

Abstract
Interest in sugarcane production has strongly increased due to its significant role in biofuel and bioenergy production. The synoptic views generated from multi-temporal remote sensing data allow us to monitor the crop vigour during its lifecycle. Despite the influence of other factors, variation in crop spectral response over an area is in part explained by local variation of soil attributes. The objective of this work was to assess the relationship between spectral data and soil attributes to support site-specific management. The study area was located in Santa Maria da Serra (Sao Paulo). For physical and chemical routine characterizations, soil samples were collected at two depths from 130 locations. Cone index and water content measurements were made at almost 900 sampling points using a hydraulic-electronic penetrometer. The *Green Vegetation Index* was calculated from three Landsat 7/ ETM+ images after atmospheric corrections. Multivariate analyses were carried out. Two models were selected with three (clay, water contents and cation exchange capacity) and four (clay, water, organic matter, and magnesium contents) variables. They explained respectively 39% and 58% of total variation. The results support the fundamental assumption of the work that variation in crop spectral response over an area is in part explained by local variation of soil attributes.

Key Words
Soil site specific management, remote sensing, multi-spectral data, GVI vegetation index.

Introduction
Reflectance is the most analyzed physical phenomenon in remote sensing applications, where vegetation indexes has been employed to monitor the vigor of the vegetation cover on global or regional scales (Miura *et al.* 2001). The synoptic views generated from multi-temporal remote sensing data allow to monitor the crop vigor during its lifecycle. In relation to sugarcane spectral response, Machado *et al*. (1985) stated that many bio-physical factors are involved, such as plant structure and geometry, as well as the size, anatomy and age of leaves. For sugarcane plantation spectral response, besides genetic and morphological differences between varieties, phenological stages and climatic conditions are also important. In Brazil, Joaquim (1998), Machado (2003), and Benvenuti (2005) have related sugarcane spectral response with bio-physical crop parameters and yield. Despite the great influence of the mentioned factors, the variation of crop spectral response over an area could be also explained partially by local variation of soil attributes, information that could be applied in agricultural management. Lourenço (2005) studied the relationship between sugarcane plantation, plant and soil attributes. The author stated that 30% of the observed variation of the NDVI vegetation index was due to local variation of soil attributes. The objective of this work was to assess the relationship between spectral data and soil attributes to support the crop site-specific management in a commercial area in Sao Paulo State.

Methods
Study area and sampling scheme
The studied area encompassed 15 plots occupying 150ha cultivated with a medium maturation sugarcane variety. General topography is gentle (0.05m/m), with increasing slopes until 0.13m/m at the lower part of the hillsides. Main soil types occurring in the area include Typic Hapludox (Red Yellow Latosols medium textured) and Typic Quartzipsamments, both with base saturation under 50%. For physical and chemical routine characterizations, soil samples were collected from 130 DGPS georeferenced sampling points at two depths, 0-0.25m and 0.25-0.50m. Cone index and water contents measurements were also made at almost 900 sampling points using a hydraulic-electronic penetrometer. Figure 1 illustrates the studied area and the soil sampling locations. A total of 42 soil attributes were evaluated.

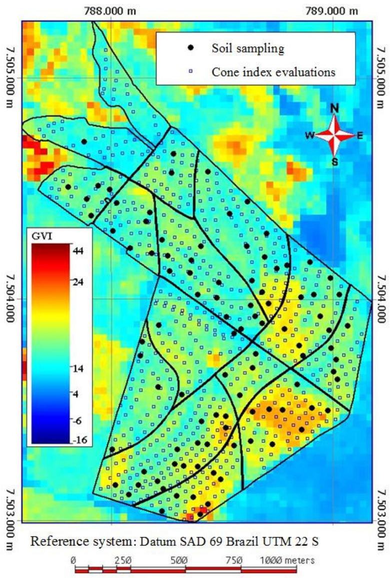


Figure 1. Location of the soil sampling points and cone index evaluations within 15 plots in studied area, with the GVI index map layout underneath.

Remote sensing data

The vegetation index GVI (*Green Vegetation Index*), originally described by Kauth and Thomas (1976) was calculated by equation 1, as described by Crist (1985). Three Landsat 7/ ETM+ images were analyzed, two of them were being acquired during the maximum vegetative crop growth phase, in January and February, and the third in May, at the beginning of the sugarcane maturation phase. In view of their multi-temporal character, the spectral data were previously submitted to atmospheric corrections before vegetation index calculations by applying the software SCORADIS (Zullo Jr 1994). The analyses were performed in a GIS environment.

$$\mathbf{GVI = - 0.1603*b1 - 0.2819*b2 - 0.4934*b3 + 0.7940*b4 - 0.0002*b5 - 0.1446*b7} \quad (1)$$

Where: b1(blue, 0,45-0,52µm), b2 (green, 0,52-0,60µm), b3 (red, 0,60-0,70µm), b4 (NIR, 0,76-0,90µm), b5 (MIR, 1,55-1,75µm), and b7 (MIR, 2,08-2,35µm) of Landsat/ ETM+sensor.

Statistical analysis

The relationship between the spectral response of sugarcane plantation and soil attributes was assessed by multiple linear regression analyses, employing the software Statistica 6.0 and adopting the stepwise method for selecting variables. Despite of having a greater density of soil observations in the study area, only one hundred sampling points, for what there were soil attributes data for both depths, were chosen to perform the multiple regression analyses. To perform these analyses, the values of the distinct soil attributes from one sampling point or geographical location (independent variables) were correlated with the correspondent values of the green vegetation index at the same geographical location (dependent variables).

Results

The results obtained include two multivariate models which are described by the equations 2 and 3 below. The first model (eq.2) for green vegetation index at maximum vegetative crop growth phase could explain approximately 39% of total variation observed on sugarcane spectral response over the studied area. Clay content at 0.25-0.50m could explain 25.4%, water content in the same depth added 9.3%, and CEC at 0-0.25m explains the last 4% of the observed variation of the GVI index. Model is significant ($P<0.00000$) with 95% confidence level, and the Shapiro-Wilk test demonstrated that residues distribution is normal ($W = 0,982$, *p*-valor = 0,173). These results are greatly coherent in view of the fact soils in the studied area are medium to sandy textured, with low contents of organic matter. These factors both determine low water retention and low CEC, which affects crop growth and vigor during crop lifecycle and could be characterized by remote sensing data.

$$GVI\_feb25 = 7.96695 + 0.02035*clay\ p2 + 0.215961*water\ content\ p2 + 0.05366*CEC\ p1\ (r^2=0.387) \quad (2)$$

Where: p1 corresponds to the 0-0.25m depth, p2, 0.25-0.50m depth, and CEC, cation exchange capacity.

The performance of the second model (eq.3) for green vegetation index at the beginning of the sugarcane maturation phase was superior and could explain approximately 58% of total variation observed on sugarcane spectral response over the studied area. In this case, organic matter content at 0.25 to 0.50 m was related with the major variation (42%) observed on sugarcane spectral response, followed by water content (8.1%), clay content (5.5%), and magnesium content (2.7%). Model is also significant ($P<0.00000$) with 95% confidence level, and the Shapiro-Wilk test demonstrated that residues distribution is normal ($W = 0.98375$, *p*-value 0,234). In May the climate is dryer and at maturation phase the soil conditions become critical to crop development. Under such circumstances, the relative greater importance on model of sub superficial organic matter could be related with its positive effect on soil structure and water retention, which would improve soil water availability and favor water absorption by deeper roots.

$$GVI\_may16 = 7.66488 + 0.13311*O.M.\ p2 + 0.162793*water\ content\ p2 + 0.01678*clay\ p1 + 0.18583\ Mg\ p1\ (r^2=0.583) \quad (3)$$

Where: p1 corresponds to the 0-0.25m depth, p2, 0.25-0.50m depth, O.M., organic matter content, and Mg, magnesium content.

Finally, considering that clay contents of soils are mostly defined by parent material and soil genesis, data support that site specific management in this area would be concerned with soil organic matter management, to improve levels of soil net negative charge (CEC), nutrients and water contents.

Conclusion

Results are coherent with soil types occurring in the area and support the fundamental assumption of the work that the variation of crop spectral response over an area is in part explained by local variation of soil attributes.

References

Benvenuti FA (2005) Relação de índices espectrais de vegetação com a produtividade da cana-de-açúcar e atributos edáficos. Dissertação (Mestrado em Engenharia Agrícola), Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas.

Crist EPA (1985) TM tasseled cap equivalent transformation for reflectance factor data. *Remote Sensing of Environment* **17,** 301-306.

Joaquim AC (1998) Identificação de variedades de cana-de-açúcar em três classes texturais de solos, na região de Araraquara - SP, através de análise de nível de cinza em imagens Landsat/TM. Dissertação (Mestrado em Engenharia Agrícola), Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas.

Kauth RJ; Thomas GS (1976) The tasseled cap – A graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. In 'Proc. The Symposium on Machine Processing of Remotely Sensed Data, Purdue University, West Lafayette, Indiana' pp. 41-50, 1976.

Lourenço LS (2005) Aplicação da estatística multivariada no estudo da relação entre atributos do solo e da planta e a resposta espectral da cana-de-açúcar. Dissertação (Mestrado em Engenharia Agrícola), Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas.

Machado EC;, Pereira AR; Camargo MBP, Fahl JI (1985) Relações radiométricas de uma cultura de cana-de-açúcar. *Bragantia*, *Campinas* **44,** 229-238.

Machado HM (2003) Determinação da biomassa da cana-de-açúcar considerando a variação espacial de dados espectrais do satélite Landsat 7 – ETM+. Dissertação (Mestrado em Engenharia Agrícola), Faculdade de Engenharia Agrícola, Universidade Estadual de Campinas, Campinas.

Miura T, Huete A R, Yoshioka H, Holben BN (2001) An error and sensitivity analysis of atmospheric resistant vegetation indices derived from dark target-based atmospheric correction. *Remote Sensing of Environment* **78,** 284-298.

Zullo Junior, J (1994) Correção atmosférica de imagens de satélite e aplicações. 189p. Tese (Doutorado em Engenharia Elétrica), Faculdade de Engenharia Elétrica, Universidade Estadual de Campinas.

Relationships of plant height and canopy NDVI with nitrogen nutrition and yields of corn

Xinhua Yin[A] Angela McClure[A] and Don Tyler[B]

[A]Department of Plant Sciences, University of Tennessee, 605 Airways Blvd., Jackson, TN, USA 38301, Email xyin2@utk.edu, athompson@utk.edu
[B]Department of Biosystems Engineering and Soil Sciences, University of Tennessee, 605 Airways Blvd., Jackson, TN, USA 38301, Email dtyler@utk.edu

Abstract
Measuring crop nitrogen (N) status during the growing season by remote sensing of the canopy seems to be a viable N management system for variable-rate N applications, emphasizing N application in the season, and minimizing the costs of N application. This study was designed to assess the relationships of plant height and canopy normalized differential vegetation index (NDVI) with crop N nutrition and yields of corn under different cropping and irrigation systems in Tennessee, USA. A field experiment was conducted near Milan, Tennessee from 2008 through 2009. Six N application rates of 0, 60, 120, 180, 240, and 300 kg N/ha were evaluated under four different cropping and irrigation systems: continuous corn under no irrigation, corn-soybean under no irrigation, corn-soybean under irrigation, and corn-cotton under no irrigation. A randomized complete block design was used with four replicates. Plant heights, canopy NDVI indices, and leaf N concentrations during the season and grain yields at harvest were measured on an individual plot basis each year. There were significant positive linear relationships between corn yields and plant heights and between corn yields and canopy NDVI indices at key growing stages regardless of crop rotations and irrigation systems. The relationships between corn yields and plant heights and between corn yields and canopy NDVI indices became stronger as the growing season progressed. The relationships of corn yields with plant heights were stronger than those of corn yields with canopy NDVI indices, respectively, at the same growing stage under all the crop rotations. The relationships of corn yields with plant heights and canopy NDVI indices were stronger with corn rotated after soybean than those in continuous corn and corn rotated with cotton. Our results suggest that plant heights and canopy NDVI indices at key growing stages can be used to develop algorithms for in-season variable rate N applications on corn under different crop rotations and irrigation systems.

Key Words
Relationship, plant height, NDVI, nitrogen, yields, corn.

Introduction
During the past few decades, the largest increase in the use of agricultural inputs has been fertilizer nitrogen (N) (Johnston, 2000). Nitrogen fertilizer is a key input for corn production. Production fields vary greatly in the native supplying capacity of N. With N fertilizer prices reaching an unprecedentedly high level during the last few years, N fertilization should be managed more efficiently. Observations from research plots and larger production fields have indicated that crop N response is very variable, and on some poor soils in some fields more N should be recommended and much less or none in other parts of the field. The presence of spatial variability within field is a critical issue demanding careful consideration for efficient use of N fertilizers.

Presently, N fertilizer is mostly recommended to be applied at a uniform rate across the entire field in many states of USA. Overall, there is a major factor limiting N use efficiency in the current N management systems for corn. As mentioned previously, the current N management systems were developed based on a state or regional scale, and they have no capability to cope with spatial variability within individual fields. Under the current systems, corn producers use a uniform N fertilizer rate for the entire field or even the entire farm, which often results in under- and over-application of N. Several research studies on corn and wheat have found large differences in crop yield and crop N response even within an individual field (Kitchen *et al.* 1995; Vetch *et al.* 1995); which confirms the need for reliable methods to generate site-specific variable-rate N recommendations (Hergert *et al.* 1997). Therefore, in order to solve the problem mentioned above, it is essential to develop innovative N management systems that can generate variable-rate N recommendations for different areas within individual fields.

Measuring crop N nutrition status during the season by optical sensing of crop canopy seems to be a viable precision N management tool for variable-rate N applications, and minimizing cost of N application (Raun *et al.* 2001; Raun *et al.* 2002; Teal *et al.* 2006; Tubana *et al.* 2008). This new precision technology allows us to variably apply N fertilizers at a less than one squared meter resolution. Researchers have utilized on-vehicle, real-time optical sensing of crop canopy to generate normalized differential vegetation index (NDVI) values to assess crop N status. This approach enables on-the-go diagnoses of crop N deficiency, real-time applying N fertilizer in variable rates to correct those deficiencies, and precisely treating each area sensed without processing data or determining location within a field beforehand. Research on corn and wheat has shown a 15% increase in N use efficiency and significant yield increases with this approach (Raun *et al.* 2002). So far, precision N management research has been focused on wheat and corn based on canopy NDVI, and is still at the beginning phase. Fewer investigations have been documented on precision N management based on plant heights.

The objectives of this study were to quantify the relationships of corn grain yields with plant height and canopy NDVI and the relationships of plant height and canopy NDVI with plant N nutrition status at different key growing stages throughout the season.

Methods

A field experiment was conducted near Milan, Tennessee, USA from 2008 through 2009. Six N application rates of 0, 60, 120, 180, 240, and 300 kg N/ha were evaluated under four different crop rotation and irrigation systems: continuous corn under no irrigation, corn-soybean under no irrigation, corn-soybean under irrigation, and corn-cotton under no irrigation. A randomized complete block design was used with four replicates. Plant heights, canopy NDVI indices, and leaf N concentrations at critical growing stages and grain yields at harvest were measured on an individual plot basis each year. Canopy NDVI readings were recorded using a GreenSeeker® NDVI hand unit (NTech Industries, Inc., CA, USA) in June and July. Relationships among grain yields, plant height, canopy NDVI, and crop N were examined using different models.

Results

There were significant positive linear relationships between corn yields and plant heights and between corn yields and canopy NDVI indices at key growing stages regardless of crop rotations and irrigation systems. The relationships between corn yields and plant heights and between corn yields and canopy NDVI indices became stronger as the growing season progressed regardless of crop rotations and irrigation systems. The relationships of corn yields with plant heights were stronger than those of corn yields with canopy NDVI indices, respectively, at the same growing stage under all the crop rotations. The relationships of corn yields with plant heights and canopy NDVI indices were stronger with corn rotated after soybean than those in continuous corn and corn rotated with cotton. Our results suggest that both plant heights and canopy NDVI indices at key growing stages can be used to develop algorithms for in-season variable rate N applications on corn under different crop rotations and irrigation systems.

Conclusion

Plant heights and canopy NDVI indices at key growing stages of the season can be used to develop algorithms for in-season variable rate N applications on corn under different crop rotations and irrigation systems.

References

Hergert GW, Pan WL, Huggins DR, Grove JH, Peck TR (1997) Adequacies of current fertilizer recommendations for site-specific management. *In* 'The State of Site-Specific Management for Agriculture' (Eds. Pierce FJ, Sadler EJ), pp. 283-300. (ASA, CSSA, and SSSA: Madison, WI).

Kitchen NR, Hughes DF, Sudduth KA, Birrell SJ (1995) Comparison of variable rate to single rate nitrogen fertilizer application: Corn production and residual soil NO_3–N. *In* 'Site-Specific Management for Agricultural Systems' (Eds. Robert PC *et al.*), pp. 427-439. (ASA, CSSA, and SSSA: Madison, WI).

Johnston AE (2000) Efficient use of nutrients in agricultural production systems. *Commun. Soil Sci. Plant Anal.* **31**, 1599-1620.

Raun WR, Johnson GV, Stone ML, Solie JB, Lukina EV, Thomason WE (2001) In-season prediction of potential grain yield in winter wheat using canopy reflectance. *Agron. J.* **93**, 131-178.

Raun WR, Solie JB, Johnson GV, Stone ML, Mullen RW, Freeman KW, Thomason WE, Lukina EV (2002) Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. *Agron. J.* **94**, 815-820.

Teal RK, Tubana B, Girma K, Freeman KW, Arnall DB, Walsh O, Raun WR (2006) In-season prediction of corn grain yield potential using normalized difference vegetation index. *Agron. J.* **98**, 1488-1494.

Tubana BS, Arnall DB, Walsh O, Chung B, Solie JB, Girma K, Raun WR. Adjusting midseason nitrogen rate using a sensor-based optimization algorithm to increase use efficiency in corn. *J. Plant Nutr.* **31**, 1393-1419.

Vetch JA, Malzer GL, Robert PC, Huggins DR (1995) Nitrogen specific management by soil condition: Managing fertilizer nitrogen in corn. *In* 'Site-specific management for agricultural systems' (Eds. Robert PC *et al*.). (ASA, CSSA, and SSSA: Madison, WI).

Scaling of *terroir* and geospatial mapping of vineyard soils via electromagnetic induction

James Fisher

Soil Solutions LLC, P.O. Box 203, Malvern, Pennsylvania 19355, USA, Email soils@comcast.net

Abstract
Vineyard site assessment is the critical phase for high quality winegrape production. Site suitability is an important criterion; but it is also advantageous to understand the strengths and weaknesses of the landform at the outset of vineyard development, especially in regard to soil variability and pathogenicity. We conducted vineyard site analysis via geographic information systems (GIS) to determine suitability for growing *Vitis vinifera*. Geospatial mapping of subsurface soil horizons was conducted by measuring the apparent electrical conductivity (EC_a) via electromagnetic induction (EMI), to geolocate soil profiles via global positioning systems (GPS) for pedon description. By correlating EC_a values of the outlier soils with associative EC_a values, we were able to geolocate outliers. Soil chemistry, biology, pedology, surface morphometry, and micro-meteorology were evaluated and quantitatively scaled via an analytical hierarchy in order to determine site vigor. After the landform was deemed suitable for winegrape production, principal emphasis was directed to recommendations on vertical tillage methods and depths, rootstock and scion selection, liming rates, row orientation, vine density, irrigation needs, erosion control, cover cropping, canopy management, tiling, row spacing, soil amendments, and nematode control. By evaluating the analytical hierarchy, agronomic choices can be made concordant with their economic impact on quality.

Key Words
Pedology, winegrape-production-systems, mapping, viticulture, terroir, vineyard-development.

Introduction
Due to the unique morphology of the grapevine root, deep soils are of notable significance for successful viticulture. In an udic regime, the high disease susceptibility of *Vitis vinifera* requires well-drained soils for high quality winegrape production; and a well-balanced fertility program is essential due to the effects of soil nutrients upon vine vigor and berry maturation. Initiation of vineyard development requires intensive soil mapping (White *et al*. 2007) in order to detect the presence or absence of restrictive horizons (notably fragipan, claypan, duripan), variance in permeability, redoximorphic features, depth to bedrock or paralithic bedrock, perched horizon interfaces, penetration resistance, effective rooting depth (ERD), and pedotransfer functions such as texture, structure, and rock content by depth, which can be used to calculate available water capacity. By marrying the technologies of GPS, GIS, and pedology, soil mapping and scaling can be useful to strategize pre-planting soil preparations such as vertical tillage, as well as to serve as a template for variance in fruit quality, berry maturation rates, and yield.

EMI transmits a primary magnetic field at preselected frequencies to induce an electric current into a given solum, and a secondary magnetic field is created, depending upon the mineralogy of the soil solid, ionic strength of the soil solution, salinity, and the content of soil water, clay, rock, and nutrients. The values (dS/m) were heuristically stored in a compatible field computer. A geospatial map of the field site was analyzed by correlating disparities in soil EC_a within a test area (Doolittle *et al*. 1995). An analytical hierarchy was generated (Figure 1), in order to provide a comprehensive rating system which is essential in a complex system such as viticultural site assessment. In addition to providing guidelines for suitable varieties, the analytical hierarchy assists the grower in choosing cultural practices to modify an existing site. The analytical hierarchy uses a percentage system, which can be directly applied to other analytical systems, such as budget, integrated pest management (IPM), best management practices (BMP), or cropping decisions. A budget designed for site development optimally maximizes soil potential index (SPI), by allocating funds according to greatest economic benefit (Soil Survey Division Staff 1993): SPI = P-CM-CL, in which P is optimal performance of soils, CM is an index of successful corrective measures, and CL is an index of corrective measures which were not fully successful. Our aim of this process was to perform a site analysis by maximizing accuracy as well as economy of time and money.

Methods
Geospatial maps serve as reconnaissance tools for positioning soil profiles to analyze the site's pedology. By correlating the overt trends of the field's EC_a values with the results of pedology analysis, a model of variance can be inferred in a time-efficient and cost-effective manner. Results obtained from soil profile analysis, surface morphometry descriptions, soil sampling, and micrometeorological data were geolocated by GIS database. Resultant site scores determined viticultural methods. EC_a is affected by soil depth, soil and rock mineralogy, clay and crystal morphology, clay content (Doolittle *et al.* 1994), soil water, salinity, and rock content (Sudduth *et al.* 2001). The development of an analytical hierarchy assists in site selection (Itami *et al.* 2000).

Reconnaissance studies were conducted with an EM-400 Profiler (GSSI, New Hampshire) in concert with a Trimble field computer, by walking a grid with the device held at a constant pre-ordained height from the soil surface. The field site was 2 hectares (5 acres), in southeastern Pennsylvania, USA. Grid rows were staked every 3.04 meters (10 ft), oriented on the Y-axis, and extended 152 meters (500 ft). GPS was tracked and synchronized with EC_a values. After completing data acquisition, the data was transferred from the field computer to a laptop computer and manipulated with MagMapper software to create a dat.file, which was exported as a grd.file into Surfer 8.0 software to create a map (see Figure 2). A northwest-to-southeast transect was established to represent disparity in EC_a. Soil profiles were dug in pedons according to associative EC_a values. Soil water greatly influences soil EC (volumetric water content was measured at 18.1%, via time-domain reflectometry {TDR}). Pedology analysis was conducted in the field following the conventions of the US Soil Survey Staff (1993). Site description of terrain was conducted using the conventions of the National Cooperative Soil Survey (Schoeneberger *et al*. 2002). Particle size distribution and inductively coupled plasma emission spectrometry (ICP) were conducted by Logan Labs LLC, Lakeview, OH. Liming rates were calculated by assessing exchangeable bases, exchangeable Al, amphoteric Al, and sodium adsorption ratios (SAR) via the Gapon equation: $K_G= [Na^+] / (\{[Ca^{++}+[Mg^{++}]\}/2)^{-1/2}$.

Results and discussion
Field site characteristics and pedology
The Dystrudept soils represent the summit, shoulder, and backslope of the hill, in an udic water regime, at an elevation of 213 m (700 ft) MSL, at 40º North latitude, on a southern aspect at 154º, with a 4.1º slope. Mean annual precipitation is 1000 mm; mean annual air temperature is 12º C (54º F). Parent material was shale and siltstone, with an ochric epipedon. Surface morphometry ranges from convex-linear, to convex-convex at Profiles # 1 & 2, linear-convex at Profiles 3 & 4, linear-linear at the northeastern corner, and a slight (concave-concave) depression at the southeastern corner. The deep, friable, very well-drained, slightly acid, moderately permeable soils which reside on the shoulder and convex backslope of the hill varied drastically from the soils of Profile 3, which were very shallow with paralithic and lithic bedrock at 53 cm (21 in). Surface soils were dark brown (7.5YR 3/4) to brown (10YR 4/3), granular crumb to weak coarse subangular blocky, very friable with 15% channery/ 5% gravelly silt loams, underlain by strong brown (7.5YR 5/8) to yellowish brown (10YR 5/6), strong medium subangular blocky, friable, very sticky, very plastic, 20% channery/ 10% stony silty clay loams. Subsoils were reddish yellow (5YR 6/6) to pale brown (10YR 6/3), massive, firm to hard, 85% channery silty clay loams to a depth of 145 cm (57 in). Loamy-skeletal grains represent the colloid. ERD averaged field-wide at 61 cm (24 in); whereas the outlier at Profile 3 had an ERD of 45 cm (18 in).

Pedology analysis showed many fine rooting and high vesicular, tubular porosity in surface soils atop common fine rooting in the upper B horizons underlain by few and fine rooting to none below 69 cm (27 in). The slopes ranging from 4.1º - 8.4º exhibit a medium- to very high- hazard of surface runoff. Generally an accumulation of clay existed in the Bt horizon. Profile 3 lacked substantial clay cutans. The pedology of Profile 3 represented the outlier pedon, possessing a shallow bedrock at 53 cm, a feature which could adversely affect vine growth uniformity within the block. Although very little can be done to mollify a shallow soil such as this, viticultural techniques can be applied to moderate the detrimental effects of shallow soils. These techniques include – but are not limited to – vine density and usage of alternative rootstocks. Therefore the locations of such aberrations are of utmost importance. EMI can only be conducted before a trellis is installed due to the interference of metal. The pedon of profile #3 represented an EC_a reading of -25 dS/m. EC_a values were inversely proportional with rock content, and positively correlated with clay content. Total available water (TAW) capacity was 97.16 mm to a depth of 1.5 meters. ERD was 55 cm. Recommended rootstocks for this site's TAW were 101-14, or *V. riparia* Gloire (Cass, 2009), with irrigation.

Parameter	Weighting	Data	Rating	Analytical score
		Soils		
pH	0.0658	5.9	0.7	0.04606
drainage	0.3465	very well-drained	0.9	0.31185
texture	0.0308	SiL	0.75	0.0231
biology	0.0641	0 per 100 cc	1	0.0641
base saturation	0.0641	low Ca, K	0.7	0.04487
ERD	0.1288	22 inches	0.7	0.09016
		Terrain		
slope	0.0143	4.1	0.9	0.01287
aspect	0.0453	SSE @ 154	1	0.0453
convexity	0.0213	CVX/LIN	0.8	0.01704
air drainage	0.0191	excellent	0.9	0.01719
		Micro-Climate		
spring frost	0.0146	low	0.9	0.01314
GDD^C	0.0922	1159	0.75	0.06915
flowering season	0.0282	good	0.9	0.02538
ripening season	0.0564	good	0.9	0.05076
pathogenicity	0.0086	low	0.85	0.00731
		TOTAL SCORE		**83.83%**
Notes: 101-14, 420-A, Riparia 'Gloire' / vertical tillage with winged tine to 50 cm / row orientation NE-SW / aromatic whites / Pinot noir / 6000 kg ha^{-1} calcitic lime tilled in to 28 cm depth in soil.				

Figure 1. An analytical hierarchy, adapted from Itami *et al*. 2000, for an udic regime, in which a scoring key designates 100% as optimal, 70-100% as suitable for *Vitis vinifera* winegrape varietals, 50-70% as suitable for hybrid and native North American varieties; whereas sites ranking less than 50% are allocated for alternative crops. This site is suitable for *vinifera*.

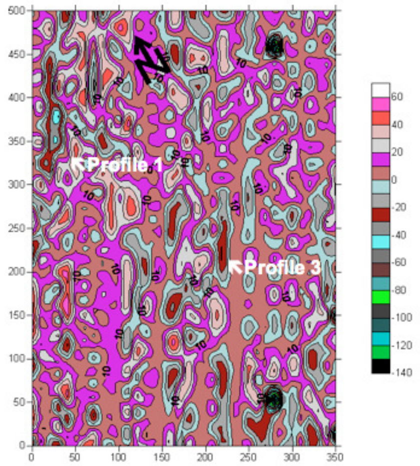


Figure 2. Geospatial map conducted at 1000 Hz, representing outlier pedon at -25 dS/m.

Variety selection: Vitis vinifera

The effect of Growing Degree Days (GDD) on berry maturation is prominent. Growing Cabernet sauvignon in a climate < 1390 GDD^C will result in off-flavors and -aromas, due to excessive production of isobutyl methoxypyrazines (Winkler, 1974). Methoxypyrazines are naturally abundant in reds particularly Cabernet sauvignon (as well as Sauvignon blanc). These methoxypyrazines begin translocation from leaves to fruit around veraison, resulting in vegetal off-flavors & -aromas if harvested before they can be dissipated sufficiently. These compounds are noticeably detrimental to wine quality at concentrations as low as 10 parts per trillion. In sites of marginal GDD, canopy management can focus on basal leaf removal pre-veraison.

Pinot noir which is rated at 1150 GDD^C (Gladstone 1992) is an exception due to its anomalous lack of production of anthocyanidids, a phenolic phytochrome which lends color attributes to red wine. 1159 GDD^C was recorded at a site proximal to this field site in 2008. Aromatic white varieties suitable for production on this site included Chardonnay, Sauvignon blanc, Albariño, Grüner veltliner, Arneis. A suitable red variety included Pinot noir.

Row orientation and vine density

Many factors determine row orientation, including but not limited to slope gradient, aspect, prevailing winds, and pathogenicity. On this site the excellent air drainage and ideal aspect can be exploited by aligning vine rows in a northeast-to-southwest orientation at 20°. This will maximize early sun exposure to reduce leaf wetness, and offset afternoon heat since *Vitis vinifera* will most efficiently photosynthesize between 20-25° C (70-80° F) (Slavcheva 1983); whereas photorespiration predominates at temperatures greater than 30° C (90° F). Recommended vine spacing for *V. vinifera* was on 1-meter centers; however 2-meter spacing is recommended on outlier soils in order to promote greater vine root density at shallower depths.

Conclusions

In concert with pedology analysis, geospatial mapping via EMI provided a general survey of the field, which served as a template to place soil profiles. Time and money was saved by using this technology; additionally, the disparity of the solum was accurately mapped to reveal and geolocate outliers. Finally, the use of an analytical hierarchy provided a score of the site strength. These techniques combine well to assess site strength and vigor in order to determine rootstock and scion selection, vine density, and ripping depth. Further work is currently underway to calibrate the skin depth of each frequency in order to better utilize EMI.

References:

Anderson-Cook CM, Alley MM, Roygard JKF, Khosla R, Noble RB, Doolittle JA (2002) Differentiating soil types using electromagnetic conductivity and crop yield maps. *Soil Sci. Soc. Am. J.* **66**, 1562-1570.

Cass A, Bazzano M (2009) *Influence of soil on wine quality*, 11th International Symposium on Soil and Plant Analysis, Santa Rosa, California, USA. July 21.

Doolittle JA, Kitchen NR, Indorante SJ (1994) Estimating depths to claypans using electromagnetic induction methods. *J. Soil Water Conserv.* **49**, 572-575.

Doolittle JA, Ealy E, Secrist G, Rector D, Crouch M (1995) Reconnaissance soil mapping of a small watershed using electromagnetic induction and global positioning system techniques. *Soil Surv. Horiz.* **36**, 86-94.

Gladstone J (1992) *Viticulture and Environment*, Winetitles, Adelaide

Itami RM, Whiting J, Hirst K, Maclaren G (2000) Use of analytical hierarchy process in cool climate GIS site selection for wine grapes. In ‘Proceedings 5th International Symposium on Cool Climate Viticulture and Oenology, Section 1B Climate and Crop Estimation’. pp. 1-8. (Adelaide: Australian Society of Viticulture and Oenology).

Soil Survey Division Staff (1993) ‘Soil survey manual’. Soil Conservation Service. U.S. Department of Agriculture Handbook 18.

Schoeneberger PJ, Wysocki DA, Benham EC, Broderson WD (2002) Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Slavcheva T (1983) Effect of temperature on photosynthesis in grapevine. *Gradinarska i Lozarska Nauka* **20**, 73-81.

Winkler AJ, Cook JA, Kliwer WM, Lider LA (1974) *General viticulture*. University of California Press, Berkeley, USA.

White R, Balachandra L, Chen D (2007) The soil component of terroir. *International Journal of Vine and Wine Sciences* **41**, 9-18.

Soil nutrient concentrations and variations on dairy farms in Australia

Cameron Gourley[A], Sharon Aarons[A], Murray Hannah[A] and Warwick Dougherty[B]

[A]Future Farming Systems Research Division, Department of Primary Industries, Ellinbank Centre, 1301 Hazeldean Rd, Ellinbank, Vic 3821, Australia, Email cameron.gourley@dpi.vic.gov.au
[B]Industry and Investment NSW, Locked Bag 4, Richmond, NSW, Australia 2753

Abstract
Nutrients are essential for dairy productivity but excesses pose a potential environmental threat. We investigated soil nutrient levels on 44 commercial dairy farms that represented a broad range of dairying operations across Australia. Soil nutrient levels were found to be highly variable within and between dairy farms. Organic and conventional dairy farms had similar pH and available K and S in pasture soils but organic dairy farms had substantially lower available P. On conventional dairy farms, soil P levels were generally high, with 80% of grazed pastures above agronomic optimum soil P concentrations. In areas where there were high stock densities, available soil nutrients were extremely high. We also found a highly significant negative relationship between soil P, K and S levels and distance of a pasture from the dairy shed. A key driver of within-farm nutrient heterogeneity appears to be stocking density of land and the resultant nutrient deposition from urine and dung.

Key Words
Soil phosphorus, potassium, sulphur, nutrient management.

Introduction
Fertiliser inputs of nitrogen (N), phosphorus (P), potassium (K), and sulphur (S), are still commonly applied to dairy pastures, despite the fact that most dairy farms are in net positive balance for all of these nutrients (Reuter 2001). Nutrient losses from dairy farming regions and eutrophication of our waterways has gained strong public and political attention and our intensive pasture systems are no longer seen as 'clean and green' (Gourley and Ridley 2005). Soil-testing has been long recognised as an important nutrient management tool, and renewed efforts in both Australia (Gourley *et al.* 2007a) and New Zealand (Edmeades *et al.* 2006), have aimed to improve their interpretation in pasture systems. In Australia, data from more than 4000 experimental trial years has recently been collated and re-analysed to improve and standardise P, K and S soil-test pasture response calibration relationships (Gourley *et al.* 2007a).

The distribution of soil nutrient levels within a farm plays an integral role in overall production and potential environmental losses. Nutrients can be unevenly distributed due to the net removal of nutrients in harvesting and grazing in some areas, and in other areas a net surplus of nutrients can occur due to manure deposition from stock, effluent applications and over-enthusiastic fertiliser use. Areas with declining nutrient availability may have reduced pasture and crop production, while areas with surplus nutrients are unlikely to generate increased production, as soil nutrient levels are often well above agronomic requirements. Excessive nutrient accumulation can contribute disproportionately to nutrient losses (Sharpley 1995) and also lead to mineral imbalances that can result in herd health problems such as grass tetany and milk fever (VandeHaar and St-Pierre 2006).

The objective of this research was to assess the spatial distribution of agronomic P, K and S concentrations and the influence of management and land-use, on a diverse range of commercial dairy farms in Australia.

Methods
Forty-four commercial dairy farms representing a broad range of geographic locations, productivity (litre milk/grazed hectare), herd size, farm size, reliance on irrigation, and soil P sorption capacity, were selected for this study (Figure 1). Four of the selected 44 dairy farms were certified organic producers, and as such did not use conventional inorganic fertilisers or chemicals. Digital mapping of each farm used aerial photographs and schematics of farm layouts to determine paddock boundaries, fence lines, total milking areas, grazed paddock areas, and distances of each paddock to the dairy. Amongst the 44 dairy farms involved in the study, farm-area ranged from 47 to 496 ha, cow numbers per farm ranged from 59 to 1930 cows, and paddocks sampled per farm ranged from 14 to 141.

© 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Figure 1. The location of the 44 dairy farms involved in the study.

Soil nutrient levels were determined in a detailed sampling of all paddocks used for pasture and crop production and areas where stock was confined (holding areas, feeding areas, sick paddocks, bull paddocks). Thirty 0-10 cm soil cores were collected along a diagonal transect across each area. Soil cores from each paddock were bulked, dried at 40ºC for 48 h and passed through a 2 mm sieve before being analysed for pH (0.01M CaCl2) (Rayment and Higginson 1992), Olsen extractable P (Olsen *et al.* 1954), Colwell P and K (Colwell 1963), KCl extractable S (Blair *et al.* 1991), and P buffering index (PBI) (Burkitt *et al*. 2008).

Results

The average soil pH, available P, K and S and PBI concentrations of different land areas from the 40 conventional and 4 organic dairy farms are presented in Table 1. While pH, Colwell K and PBI levels were similar from pastures on the conventional and organic dairy farms, Olsen and Colwell P levels were around twice as high on the conventional dairy pastures. Within the conventional dairy farms, areas with high animal densities (feeding areas, holding areas, sick paddocks, and bull paddocks) had considerably higher soil pH, P, K and S than grazed pasture soils. Nutrient loads from dung and urine are often extremely high in these confinement areas as a result of the high density of cows held for extensive time periods (Gourley *et al.* 2007b). Land used for non-dairy grazing animals had the lowest nutrient availability on conventional dairy farms and was comparable to the organic dairy pastures.

Table 1. Mean soil pH, available P, K and S and PBI levels of different land uses from 40 conventional and 4 organic dairy farms. Standard deviations are in parentheses.

Management/Use	Distance to dairy (m)	pH (CaCl2)	Olsen P (mg/kg)	Colwell P (mg/kg)	Colwell K (mg/kg)	KCl S (mg/kg)	PBI (mg/kg)
			Organic				
Pasture n=141*	625.5	5.4 (0.6)	16.7 (13.8)	65 (62)	271 (199)	18.4 (20)	302 (166)
			Conventional				
Pasture n=1773	881.4	5.3 (0.7)	35.6 (20)	127 (76)	296 (224)	23.4 (33)	263 (230)
Bull paddock n=6	444.0	5.3 (0.9)	48.8 (26)	169 (82)	703 (602)	45.3 (29)	262 (24)
Feeding areas n=12	53.1	6.8 (1.2)	319.9 (285)	1151 (1286)	4471 (3945)	263.5 (263)	321 (277)
Holding area n=13	400.4	5.8 (0.9)	143.5 (171)	510 (685)	1515 (1271)	73.8 (71)	251 (252)
Sick paddock n=16	46.9	5.6 (0.9)	71.4 (61)	280 (282)	771 (711)	27.5 (19)	178 (180)
Other animal n=104	na	5.1 (0.6)	27.4 (15)	100 (58)	269 (180)	14.6 (12)	301 (281)

* n= number of areas sampled

The soil P levels from grazed pasture paddocks on conventional dairy farms ranged between 3 and 189 mg/kg for Olsen P and 13 and 730 mg/kg for Colwell P. Only 20% of the paddocks sampled were below the recommended agronomic optimum (20 mg/kg for Olsen P; between 15 – 75 for Colwell P, depending on P buffering; Gourley *et al.* 2007a), while 50% of paddocks were two or more times the recommended agronomic optimum (Figure 2).

© 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

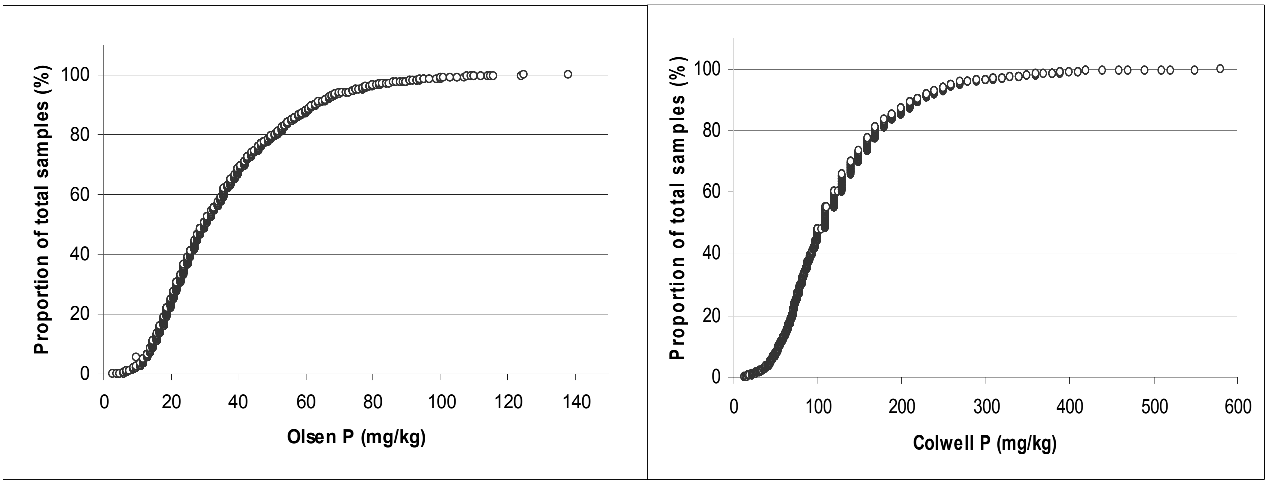


Figure 2. The proportional distribution of soil P levels determined from dairy pastures (n= 1768) from 40 conventional dairy farms across Australia.

The effect of distance-to-dairy was estimated using a fitted random coefficients model including PBI, grazing intensity, effluent application, land use, irrigation, and organic/conventional system, farm and residual error.

While individual pasture soil nutrient concentrations varied markedly between farms, there was a highly significant ($P<0.01$) relationship between distance-to-dairy and soil P, K and S concentration. For example, there was an overall 4-fold difference in Olsen P, between paddocks close to, and those furthest from, the dairy (Figure 3).

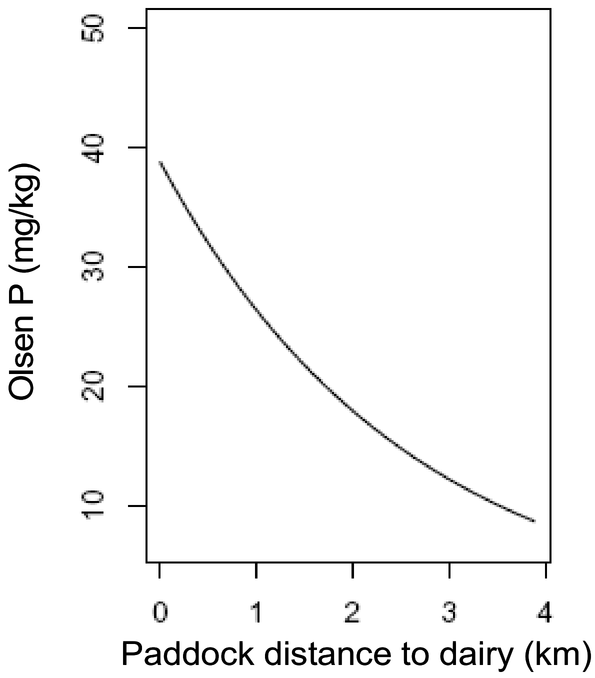


Figure 3. Partial effect of distance to dairy and Olsen P for pasture paddocks on 44 dairy farms.

Conclusion

Based on the results of this study, we conclude that there are large excesses of P, K and S on a broad range of dairy operations across Australia. The concentration and distribution of nutrients was related to farming type (organic v conventional), land use (e.g. feeding areas v grazed pastures), and distance of grazed pastures from the dairy. A key driver of within-farm nutrient heterogeneity appears to be the stock density and resultant nutrient deposition from urine and dung.

The current imbalance between nutrient inputs, primarily as feed and fertiliser, and nutrient outputs, in milk and livestock, and the uneven nutrient distribution within dairy farms, provides both an opportunity and a challenge to the Australian dairy industry. There are significant savings and productivity gains to be had from adopting a more spatially targeted approach to nutrient applications and more effectively using nutrients recycled in animal excreta. Conversely, continuing with current grazed dairy systems and nutrient management practices is likely to result in the significant accumulation of nutrients, particularly in high animal density areas, increased losses of nutrients to the broader environment, and stricter environmental standards which may limit inputs and dairy farm productivity.

References

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.

Burkitt LL, Moody PW, Gourley CJP, Hannah MC (2002) 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.

Edmeades DC; Metherall AK; Waller JE; Roberts AHC; Morton JD (2006) Defining the relationships between pasture production and soil p and the development of a dynamic P model for New Zealand pastures; a review of recent developments. *New Zealand Journal of Agricultural Research* **49***,* 207-222.

Gourley CJP, Melland AR, Waller RA, Awty IM, Smith AP, Peverill KI, Hannah MC (2007a) Better fertiliser decisions for grazed pastures in Australia. [on-line] http://www.asris.csiro.au/themes/nutrient.html#Nutrient_BFD.

Gourley CJP, Powell JM, Dougherty WD, Weaver DM (2007b) Nutrient budgeting as an approach to improving nutrient management on Australian dairy farms. *Australian Journal of Experimental Agriculture* **47**, 1064-1074.

Gourley CJP, Ridley A (2005) Controlling non-point pollution in Australian agricultural systems. *Pedosphere* **15**(6), 763-777.

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)

Rayment GE, Higginson FR (1992) 'Australian laboratory handbook of soil and water chemical methods.' (Inkata Press: Melbourne)

Reuter DJ (2001) Nutrients – farm gate nutrient balances. Australian National Land and Water Audit 2001. [On-line] Available at http://audit.ea.gov.au/ANRA/land/farmgate/Nutrient_Balance.pdf.

Sharpley AN (1995). Dependency of runoff phosphorus on extractable soil phosphorus. *Journal Environmental Quality* **24**, 920-926.

VandeHaar MJ, St-Pierre N (2006). Major advances in nutrition: relevance to the sustainability of the dairy industry. *Journal Dairy Science* **89**, 1280-1291.

Spatial variability of soil carbon at the paddock scale

Kanika Singh[A] Brian Murphy[B] Alex McBratney[A] and Brett Whelan[A]

[A]Faculty of Agriculture Food & Natural Resources, The University of Sydney, NSW 2006, Australia, Email k.singh@usyd.edu.au, alex.mcbratney@sydney.edu.au, brett.whelan@sydney.edu.au
[B]Department of Environment, Climate Change and Water NSW, Email Brian.Murphy@environment.nsw.gov.au

Abstract
This work reports on a dynamic sampling and monitoring strategy to measure soil carbon at the paddock scale. The current method used in Australia for estimating soil carbon is given in McKenzie *et al*. (2000). It is based on using samples from within a single 25m quadrant to quantify the carbon content of a soil unit. The soil carbon sampling design presented here aims to take into account the spatial variability of soil carbon at the paddock scale. A systematic random sampling strategy was carried out to obtain the carbon data for the whole paddock and to study the factors accounting for the carbon variability. This is part of a larger study is to devise a more efficient and accurate sampling scheme incorporating ancillary information such as crop yield, soil and landscape information (soil ECa, terrain parameters). The results here show that at the paddock-scale there is a decrease in soil carbon content and carbon density with depth. There is also significant, well structured spatial variability across the paddock, and this variability decreases with depth. From this study it is reasonable to conclude that sampling within a 25 m x 25 m square may provide an estimate of carbon within that square but is not likely to provide the detail to accurately monitor soil carbon across a whole paddock.

Key Words
Soil carbon, quadrat, bulk density, soil carbon variability.

Introduction

The standard method for estimating soil carbon in Australian soils (McKenzie *et al.* 2000) recommends sampling within a 25 m x 25 m square quadrat per soil unit. This technique can quantify C accurately for that quadrat. This has several scientific advantages when comparing the soil carbon levels under different land management practices across paired sites and in soil monitoring programs when soil carbon levels are compared through time (McKenzie *et al.* 2000). However the spatial variation of soil C across a whole paddock is likely to be far greater than the variation within a single quadrat. Therefore the measurement of soil carbon stores at the paddock scale is unlikely to be effectively measured using the standard method of a 25 m quadrat. This has important for the accounting and auditing of soil carbon.
The aims of this study were:

- To quantify and map the spatial variability in carbon density within a paddock and,
- To evaluate the potential errors in using the single 25 m quadrat to predict soil carbon stores at the paddock scale.

This work is part of a larger program to test the effect of different management practices on increasing the soil carbon content in the soil. The overall aim is to ascertain whether variable rate treatments, rather than uniform management practices (Taylor, McBratney *et al.* 2007), would improve carbon sequestration within a paddock,

Materials and method

Study site

The site, 7east Hatton is in Central West NSW, the governing soil type is a Red Chromosol with traces of manganese and charcoal in the lower depths. There is a depression in the centre of the eastern half of the paddock where the manganese content is high. Clay content increases with soil depth in the paddock and the paddock is under cropping.

Experimental design

A 100 m regular grid, aligned with the vehicle tramlines, was overlain on the whole paddock. Random samples were taken within each cell. This systematic random sampling gave 75 sampling points across the paddock. Another 15 secondary sampling points were randomly placed at 10 m or 1 m spacing from primary sampling points for an estimation of small scale variability. Sampling points were located using a decimetre accurate Trimble DGPS with Omni star-HP correction.

Sampling and analysis

A hydraulic corer mounted at the back of a vehicle was used for the study. The soil cores were cut into 0- to 10, 10- to 20, 20- to 30 and 30- to 50 cm depth increments for the analysis. The soil at the time of sampling was in a moderately moist condition to ensure coherent, intact cores were taken with little disturbance. The depth of the hole from which the core was taken was measured and compared to the length of the core to ensure that no compaction was occurring and that the core reflected the bulk density of the undisturbed soil. The samples were placed in labelled plastic bags and transported to the laboratory for analysis. The samples were weighed and a sub sample was taken to measure the moisture content. The soil was air dried at 40^{o}C for 48 h, and passed through a 2-mm mesh sieve. The soil was further grounded to pass a 53 micron mesh sieve. The soil carbon percentages were determined with a CHN –Vario Max CNS analyser. Bulk densities were estimated with the moisture content of sub sample, wet weight and the volume of the core. The carbon percentage values and the bulk density were used to calculate the carbon density for each core in kg/m^2. The spatial distribution of carbon density for the whole paddock was estimated using kriging techniques (Whelan *et al.* 2001) from the carbon densities of the individual cores. The spatial distribution of bulk density and soil carbon content were described by global variograms. The total carbon store to 50 cm for the whole paddock (tonnes) was estimated from the kriged spatial distribution of soil carbon density.

Formula

CD (kg/m^2) = Carbon content (kg/kg) x BD (kg/m^3) x Depth (m), where BD is the bulk density and CD is the carbon density.

Results and discussion

Soil carbon values show a decreasing trend with depth and there is a rise in bulk density with depth. The spatial variation in both properties also generally decreases with depth (Figure 1). Given this data, the calculated soil carbon density also shows substantial variation across the paddock. It varies from 50 to 100 kg/m^2/50cm (see Figure 2).

This indicates that the location of a single 25 m quadrat can result in up to 100% variation in the soil carbon density within the paddock and that the selection of the location for the quadrat to measure the soil carbon is a critical decision in estimating soil carbon levels for different land management practices. One advantage however is that there are clearly areas where the soil carbon density is relatively uniform. A potential serious problem for the 25 m quadrat method arises if the quadrat happens to be placed on a location which is a "hotspot" for soil carbon or an unusually low spot, where the critical levels of soil carbon are unusually low (see Figure 3).

The spatial distribution of the soil carbon density based on the grid of soil cores and kriging suggests there are several of these in the paddock. However, as some of these hotspots and unusually low values maybe based on soil carbon values from a single core, this may not necessarily be the case for the standard sampling from a 25 m quadrat which usually includes at least 10 soil cores within the 25 m quadrat. The full analysis of the relationships between the soil carbon densities with spatial information about the paddock including yield data, EM surveys, DEM data, landform analysis etc. is still being processed.

Conclusion

Soil carbon density shows significant spatial variability across the study paddock. The random location of a single 25 m quadrat has been shown to be ineffective in predicting the soil carbon store at the paddock scale. It has also been shown that the selection of the location of a 25 m quadrat in the paddock can have a large affect on the amount of soil carbon measured Further analysis will indicate whether the use of such spatial information on crop yields, EM, DEM's, land form and SPOT imagery will enable more effective selection for the location of a single 25 m quadrat to provide information on soil carbon stores for scientific reference sites. This analysis will also enable recommendations to be made about the most effective sampling methods to estimate soil carbon levels at the paddock scale for soil carbon auditing. Future work will also look into using variable-rate management to influence soil carbon at the paddock scale.

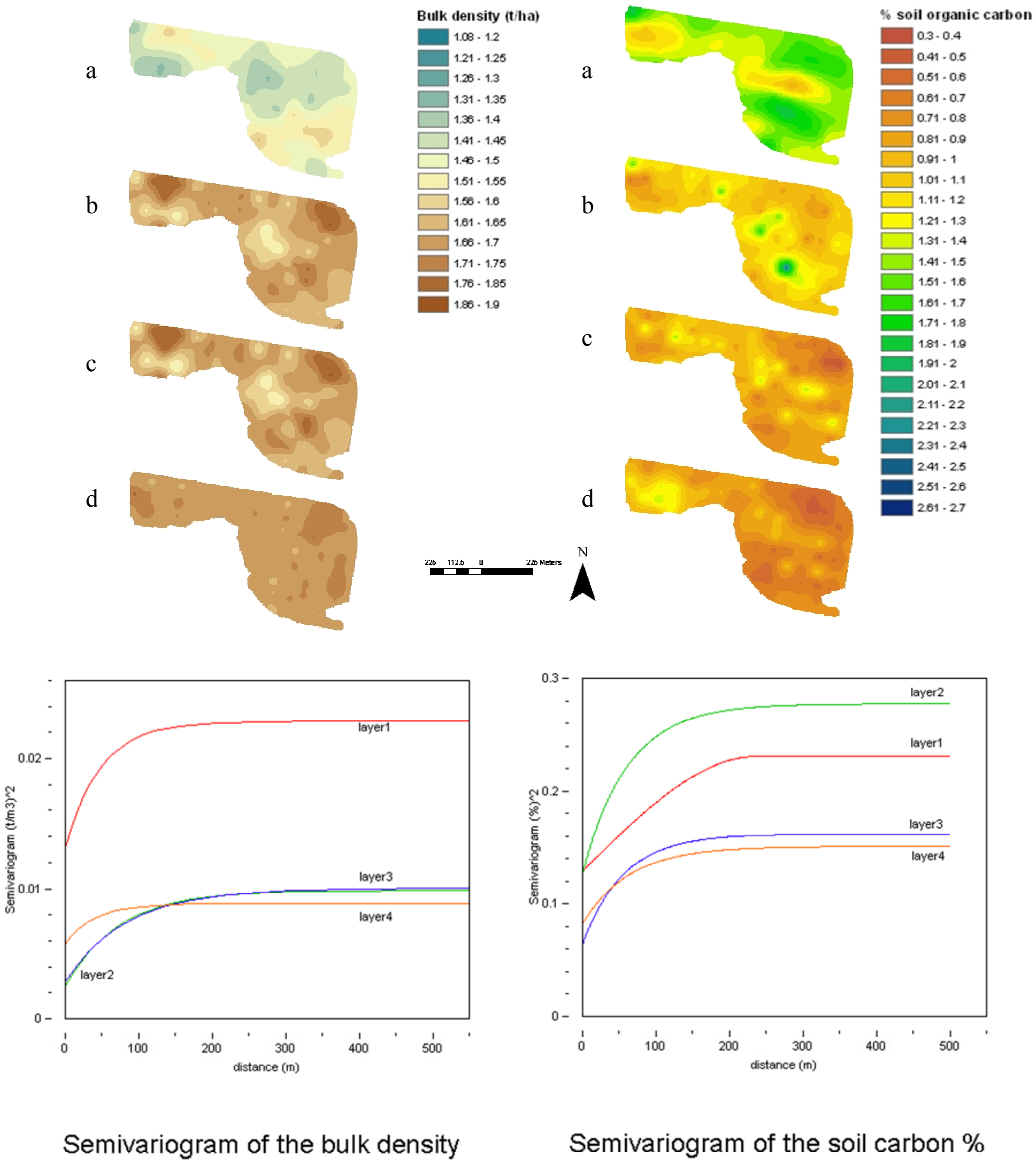


Figure 1. The spatial variability of bulk density and carbon density within a paddock.
Key- a. 0- 10 cm (layer 1), b. 10 – 20 cm (layer 2) , c. 20 – 30 cm (layer 3) , d. 30 – 50 cm (layer 4).

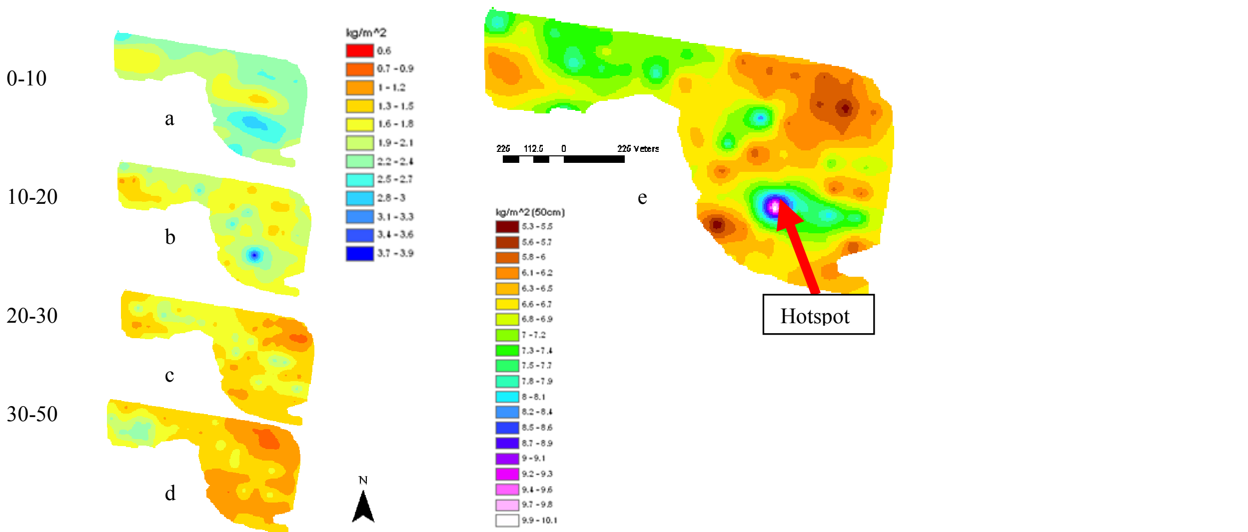


Figure 2. Carbon density(CD) a.CD at depth 0- to 10-cm, b.CD at depth10- to 20-cm, c. CD at depth 20-30-cm, d. CD at depth 30-to 50-cm and e. average carbon density of the whole profile (50cm) with hotspot. Some caution is required in interpreting hotspots as these are from a single core.

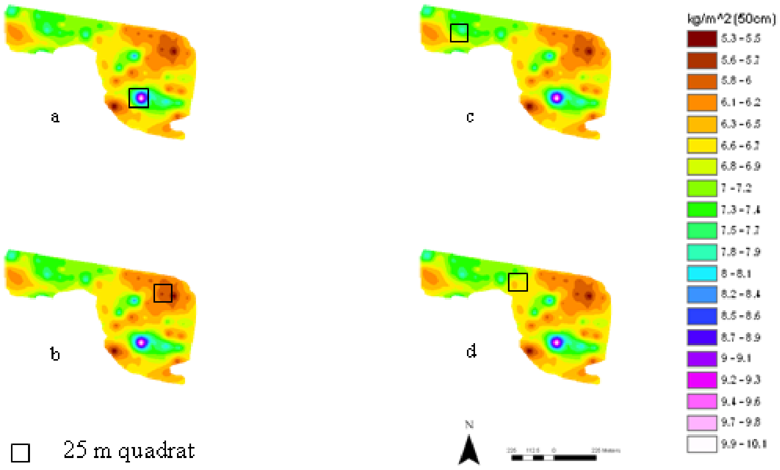


Figure 3. The 25 m quadrat placed randomly on the paddock a. quadrat covering the hotspot b. quadrat covering the low soil carbon area c. quadrat covering moderate soil carbon area and d. quadrat between the moderate and low soil carbon area. Ideally the 25 m quadrat should be placed in an area with a relatively uniform soil carbon density.

References

McKenzie N, Ryan P, Fogarty P, Wood J (2000) Australian Greenhouse Office, Technical Report 14.

Taylor JA, McBratney AB *et al*. (2007) Establishing management classes for broadacre agricultural production. *Agronomy Journal* **99**(5), 1366-1376.

B.M.Whelan, A.B. McBratney, B. Minasny. 2001. Vesper - Spatial Prediction Software for Precision Agriculture. In 'Proceedings of the 3rd European Conference on Precision Agriculture, Montpellier, France, ECPA 2001' (Eds. Grenier G. and Blackmore S), pp. 139-144. Agro-Montpellier, Montpellier, France.

© 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

The use and impacts of glyphosate and pyraclostrobin in soybean and sugar beet farming: selected socio-ecological issues in Michigan's Huron, Sanilac, Lapeer and Tuscola counties, USA

Lesley Atwood[A] and James Bingen[B]

[A]CARRS Masters of Science Graduate Student, Michigan State University, East Lansing, MI, USA, Email atwoodle@msu.edu
[B]Faculty of CARRS, Michigan State University, East Lansing, MI, USA, Email bingen@anr.msu.edu

Abstract
Huron, Sanilac, Lapeer and Tuscola counties, Michigan, USA, currently cultivate eighty-seven percent of the land largely in soybeans, sugar beets, corn and winter wheat. Both glyphosate and pyraclostrobin are regularly applied in the region to manage pests. A public discussion emerged in the region regarding the long-term effects on soil quality and the future viability of agriculture.This research seeks to identify and discuss the inter-related socio-ecological dimensions of the long-term use of glyphosate and pyraclostrobin on soybean and sugar beet production in Michigan's Thumb region using a multidisciplinary approach. In-depth interviews with farmers will identify the social and cultural pressures of farm management in the region, and commonly referenced soil quality indicators. Potential synergies and/or long-term effects of glyphosate and pyraclostrobin on soil quality will be examined using a data-driven meta-analysis of previously conducted soil quality and pesticide research. This type of analysis encompasses an array of researches and determines if insignificant results of single experiments are statistically significant across multiple experiments. Results of this research will not only benefit the Michigan agricultural community, but also raise critical questions regarding the long-term viability of many agricultural practices.

Key Words
Genetically modified, agriculture, soil quality, Ethnopedology, multidisciplinary.

Introduction

Current situation

Eighty-seven percent of the land in Michigan's Huron, Sanilac, Lapeer and Tuscola counties, Michigan's Thumb region, is cultivated largely with soybeans, sugar beets, corn and winter wheat (NASS 2007). In this region, eighty-five percent of the land is farmed conventionally where it is common to grow soybeans (*Glycine max* (L.) Merr.) that are genetically modified to resist glyphosate, a broad spectrum herbicide. Fungicides with the active ingredient pyraclostrobin (a broad spectrum fungicide), e.g. BASF's Headline fungicides, are also used on the same farms to eliminate pathogenic fungi. Approximately 1.3% of the cultivated area in the region, or 18,500 acres, is farmed organically (NASS 2007). The organic farms do not use genetically modified seeds or apply glyphosate and pyraclostrobin. Given the close proximity of these different crop management strategies, questions regarding the region's soil health and quality are frequent and controversial topics of discussion in the region.

The region's loamy till parent materials and relatively fine soil texture creates a rich landscape for the production of a variety of crops, as long as the soils are provided with ample subsurface drainage. But the more than ten years of glyphosate applications and five years of pyraclostrobin applications may be compromising the soil health in this region, and consequently the future of the region's economic well-being. A growing public discussion about the relationship between the long-term use of glyphosate and pyraclostrobin and observed changes in the region's soil quality inspired this research. Are these crop management technologies, often promoted as sustainable, undermining the viability of the region's soils and the livelihoods of its farmers? This research seeks to identify and discuss the inter-related socio-ecological dimensions of the long-term use of glyphosate and pyraclostrobin on soybean and sugar beet production in Michigan's Thumb region.

Literature review and research issues

Agriculture in the United States changed significantly when genetically engineered varieties of soybeans, corn and cotton became commercially available in the late 1990's. Genetically engineered, or genetically modified (GM), crops undergo alterations to their DNA to make, modify, improve or develop the crop for production and management purposes (ERS 2009). GM-varieties became increasingly popular in the US as

© 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World
1 – 6 August 2010, Brisbane, Australia. Published on DVD.

farmers learned more about the perceived benefits associated with these varieties. GM-seeds, in particular, are touted for their ability to increase crop yields, efficiently manage pests, tolerate climatic variation, and decrease labor and input costs (Monsanto Company 2009). From a peak of 87% in 2007, the percentage of GM soybeans planted in Michigan in 2008 and 2009 declined from 84% and 83% respectively (ERS 2009).

The attractive qualities of GM-crops accelerated farmers' willingness to accept and cultivate these varieties. Rapid integration into the agricultural system across the United States spurred research on various ecological implications including: the likelihood of cross contaminations; the impacts on non-target species; the emergence of superweeds; and, the loss of seed biodiversity. Farm management decisions are dependent on how farmers interpret the benefits and drawbacks of cultivating GM-varieties.

There is little question that the market value of the harvested crop weighs heavily on the farmers' decision to use a seed. At the same time, several researchers have identified how farmers vary in their motivations ranging from purely economic gains to valuing environmental and social incentives (Sall *et al.* 2000). Guehlstorf (2008) concludes that farmers integrate, rather than mutually exclude, economic prosperity, environmental health and social well-being. Overall, these results show that each farmer individually decides what is important and then chooses a management strategy. In short, farmers identify with the phrases "appropriate farm management" and "healthy soils" differently because each farmer is socially, politically, and philosophically situated. This means that the way farmers assess and monitor soil quality also varies. Romig et al. (1995) studied the various ways farmers in Wisconsin assess soil health and quality in the field. After consulting farmers, they identified the natural indicators farmers commonly use to identify a healthy soil. This work is also one of the few ethnopedological studies on modern conventional farmers. This variability in how farmers make soil management decisions creates challenges for studying soil health issues and for developing practical solutions, including ways for dealing with the long-term impacts of glyposate and pyraclostrobin.

The available research results on the impacts of glyphosate and pyraclostrobin on soil quality further complicate studies on soil health. To date no studies have examined the combined effect of applying both glyphosate and pyraclostrobin to the same field, as commonly practiced by farmers. Application of these pesticides in the same field may have synergistic effects, especially on microbial communities, which actively breakdown these chemicals in the soil (Bartlett *et al.* 2002; Duke *et al.* 2003). Reliance on these biotic communities to remove both glyphosate and pyraclostrobin from the soil may, in the long-term, have deleterious effects on the soil's quality.

The following experimental results are separated based on the effects each pesticide has on the soil. With GM glyphosate-resistant crops, glyphosate is often applied over the top of the field accounting for the more than six-fold increase in use between 1992 and 2002 (Gianessi and Reigner 2006). Glyphosate absorbs quickly into soil particles and is rapidly degraded by soil microbial communities (Duke *et al.* 2003). Exposure to glyphosate for numerous years increases plant propagules and rates of microbial activity, measured through soil respiration concentrations, without adverse effects (Cerdeira and Duke 2006). Glyphosate also directly and indirectly influences the number of fungi present because it affects how fungi and microorganism's interact (Wardle and Parkinson 1990). Overall, these studies show that in the short- and long-term, glyphosate increases the rate of activity in soil microbial communities.

BASF Corporation's pyraclostrobin, a broad spectrum strobilurin fungicide, became commercially available in 2002. Resistance to pyraclostrobin can occur through a single point mutation in both basidiomycetes and ascomycetes (Grasso *et al.* 2006). Pyraclostrobin readily forms mobile metabolites with decreased toxicity and it is absorbed by microbes and through photolysis (Bartlett *et al.* 2002). Ragsdale and Koch (2008) compiled scientific references that demonstrate how pyraclostrobin adversely affects entomopathogenic fungi, naturally occurring host specific bioinsecticides, and how it encourages the development of aphid populations by eradicating fungal disease within the population. This adverse effect mitigates soil microbial interactions which imbalances biotic communities.

This research will explore three dimensions of the future status of the soil quality and agricultural viability of Michigan's Thumb region. First, the social and cultural pressures farmers navigate to make farm management decisions. Secondly, how modern farmers assess soil quality and perceive the region's future with consistent use of glyphosate and pyraclostrobin. Lastly, this research will explore ecological impacts and potential synergies that exist with joint use of these chemicals in the scientific literature. In summary, our working hypothesis is that farmers in Michigan's Thumb region rely on soil quality indicators to make farm management decisions because they want to maximize productivity without depleting the rich soils. In addition, this research may find that while farmers have observed adverse affects from using glyphosate and pyraclostrobin, they are socially influenced to use new synthetic chemicals rather than rebuilding natural ecological services within the system. Ultimately, the lack of scientific evidence on the long-term use of these pesticides inhibits farmers from diversifying their farm management tactics.

Methods

This research will be conducted November 2009 - May 2010 to fulfill part of L. Atwood's Master's of Science degree. To examine these inter-related socio-ecological relationships, a multidisciplinary approach utilizing both qualitative and quantitative methods will be used. Efforts will be made to interview farmers who have previously participated in soil test research so that relationships between these data sets can be analyzed. In-depth interviews will be used to document farmers' farm management decisions, pesticide usage, and soil quality observations. During the in-depth interviews, farmers will be asked to describe their current farming practices, why they decided to farm this way, and what they perceive as the benefits and drawbacks of their management practices. Farmers will also be asked to describe what environmental impacts, if any, they have observed in the field and if they relate these adverse affects to the long-term use of glyphosate and pyraclostrobin. Finally, farmers will be asked to describe the relationship between the region's current soil quality and the future of agriculture in the region. All interviews will be taped, transcribed and analyzed using a thematic content analysis. Emergent concepts and themes from the interviews will be compiled and coded using NVivo, a coding and qualitative management program.

To determine if there are interactions and/or long-term effects of glyphosate and pyraclostrobin on soil quality, data from previously conducted soil quality and pesticide research will be compiled and analyzed using an emergent technique similar to a meta-analysis. Data-driven meta-analyses of published, peer-reviewed literature can reveal significant results that are often concluded as insignificant within a single experiment, but can be statistically significant across multiple experiments. This method was previously used to analyze laboratory experiments on the impacts of GM plants on arthropod natural enemies to determine if result summaries influence conclusions and future research (Lovei *et al.* 2009). This type of comprehensive quantitative analysis will provide a more holistic and inclusive look at the potential impacts of glyphosate and pyraclostrobin. Relevant peer-reviewed and Michigan State University Extension research will be compiled. Data-driven data analysis of these experiments will then be conducted.

Significance

Inter-related socio-ecological issues are common in today's societies, but academics often research these issues independently. Since Michigan's Thumb region is economically dependent on agriculture, this type of research will aide in their efforts to sustain agricultural viability, which also involves conservation of the region's soils. Overall, these results will not only benefit Michigan's agricultural community, but also raise critical questions regarding the long-term viability of many agricultural practices.

References

Bartlett DW, Clough JM, Godwin JR, Hall AA, Hamer M, Parr-Dobrzanski B (2002) The strobilurin fungicides. *Pest Management Science* **58**, 649-662.

Cerdeira AL, Duke SOJJoEQ (2006) The current status and environmental impacts of glyphosate-resistant crops: a review. **35**, 1633.

Duke SO, Baerson SR, Rimando AM (2003) Herbicides: Glyphosate. In 'Encyclopedia of Agrochemicals'. (John Wiley & Sons: New York).

Economic Research Services (ERS) (2009) Adoption of Genetically Engineered Crops in the U.S.: Soybeans Varieties. United States Department of Agriculture.

Gianessi L, Reigner NJCLFWDC (2006) Pesticide use in US crop production: 2002.

Grasso V, Palermo S, Sierotzki H, Garibaldi A, Gisi U (2006) **Cytochrome** gene structure and consequences for resistance to Qo inhibitor fungicides in plant pathogens. *Pest Management Science* **62**, 465-472.

Guehlstorf NP (2008) Understanding the Scope of Farmer Perceptions of Risk: Considering Farmer Opinions on the Use of Genetically Modified (GM) Crops as a Stakeholder Voice in Policy. *Journal of Agricultural*

& Environmental Ethics **21**, 541-558.

Lövei GL, Andow DA, Arpaia SJEE (2009) Transgenic insecticidal crops and natural enemies: a detailed review of laboratory studies. **38**, 293-306.

Monsanto Company (2009) Benefits of Our Products. http://www.monsanto.com/products/benefits.asp

National Agricultural Statistical Services (NASS) (2007) The Census of Agriculture. United States Department of Agriculture.

Ragsdale DW, Koch KAJPotICPTC (2008) Fungicides: Do They Adversely Affect Beneficial Insect Pathogens in Multiple Cropping Systems?

Romig DE, Garlynd MJ, Harris RF, McSweeney K (1995) How farmers assess soil health and quality. *Journal of Soil and Water Conservation* **50**, p229(228).

Sall S, Norman D, Featherstone AM (2000) Quantitative assessment of improved rice variety adoption: the farmer's perspective. *Agricultural Systems* **66**, 129-144.

Sandor JA, WinklerPrins AMGA, Barrera-Bassols N, Zinck JA (2006) The Heritage of Soil Knowledge Among the World's Cultures. In 'Footprints in the Soil: People and Ideas in Soil History'. (Ed. BP Warkertin) pp. 43-84. (Elsevier: Boston, MA).

Wardle D, Parkinson D (1990) Influence of the herbicide glyphosate on soil microbial community structure. *Plant and Soil* **122**, 29-37.

Williams BJ, Ortiz-Solorio CA (1981) Middle American Folk Soil Taxonomy. *Annals of the Association of American Geographers* **71**, 335-358.

© 2010 19th World Congress of Soil Science, Soil Solutions for a Changing World
1 – 6 August 2010, Brisbane, Australia. Published on DVD.