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An agricultural decision support tool for wheat-maize cropping on the North China Plain based on a spatially-referenced biophysical process model of water, nitrogen and crop growth

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Abstract
The essential water and N fluxes for irrigated wheat-maize systems were quantified in a one hectare plot in Fengqiu County in the North China Plain (NCP). A spatially-referenced, process model (WNMM) was developed to simulate key water, carbon and nitrogen dynamics, crop growth and agricultural management practices. An agricultural decision support tool (ADST) based on WNMM dynamically coupled to a geographical information system (GIS) was developed to provide best management practices (BMPs) for irrigation and fertilizer use county-wide. Adoption of BMPs would reduce annual N fertilizer use by 20-23% and provide annual water savings of AUD10-45 per ha for no significant change in crop yield. The potential net benefits of the project were estimated at AUD216 million.

Key Words
Agricultural decision support tool, water and nitrogen dynamics.

Introduction
Irrigation and fertilizer use have contributed to the success of food production in China, particularly on the North China Plain (NCP), an important grain production base for China. However, there is growing concern about the environmental effects of intensive agriculture. Because of excessive use of water and nitrogen (N) fertilizer, groundwater resources have been over-exploited and nitrate (NO_3^-) concentrations in groundwater have risen to >50 mg NO_3-N L^{-1} (Norse and Zhu 2004). Emission of the greenhouse gas nitrous oxide (N_2O) have also increased, with agriculture now accounting for >60% of total N_2O emissions in China (Zheng *et al*. 2004). For sustainable high production, better management of water and N fertilizer is required, balancing both economic and environmental interests. Meeting this need requires a comprehensive understanding of the dynamics of water and N in the crop-soil system, the impact of soil and environmental variables and management practices on these dynamics, and socio-economic constraints. Such an understanding can be achieved through process-based simulation modelling, dynamically linked to a geographic information system (GIS), and leading to the identification of best management practices (BMPs) that can form the basis of an agricultural decision support tool (ADST).

We applied this approach to intensive wheat-maize rotations under irrigation on the NCP. This required comprehensive field measurements to quantify all essential water and N fluxes, the development of a spatially-referenced (GIS-based) biophysical model (WNMM), and development of a user-friendly ADST to help policy makers and advisers identify BMPs to improve farm productivity and regional environmental outcomes.

Methods
Field measurements
The project was carried out in Fengqiu County, Henan Province, which represented some of the major soil types in the NCP supporting irrigated wheat-maize rotations. The farmers sow winter wheat and summer maize in October and June and harvest in June and September, respectively. For wheat, N fertilizer is applied at sowing and in early spring at the rate of about 150 and 100 kg N/ha, respectively, and irrigations of 100 mm each are applied during the growing season. For maize, N fertilizer of 100 and 80 kg N/ha is applied in mid-July and August, respectively, usually followed by irrigations of 100 mm each. Groundwater was the main source of irrigation water.

A one ha (100 x 100 m) experimental plot (OHEP) was set up to carry out detailed field measurements of water and N fluxes and to parameterize the WNMM model. Some important properties of the dominant soil type are given in Table 1.

Table 1. Selected properties of the profile of the dominant soiltype at the experimental site.

Soil type[A]	Depth layer (cm)	pH (water)	Organic matter (g/kg)	Total N (g/kg)	Texture
Ochric Aquic Cambisol	0-20	8.5	10	1	Sandy loam
	20-60	8	7.3	-	Silty clay loam
	60-170	8	1.4	-	Loamy sand

[A]Research Group of China Soil Taxonomy System (1995)

Crop growth and changes in soil water content were measured and drainage losses below the root zone calculated from a daily water balance calculated for successive soil layers to 1.7 m depth. Nitrate concentrations in the soil solution, NH_3 volatilization, denitrification and N_2O emissions were measured directly. Soil temperatures at different depths were calculated from heat fluxes.

Development of the water and nitrogen management model (WNMM)

The WNMM model simulates key processes of water, C and N dynamics in the topsoil and subsoil during crop growth. Nitrogen fertilizer is an input and soil N transformations are simulated from the decomposition and mineralization of fresh crop residues and soil organic organic matter, microbial immobilization of N, nitrification, NH_3 volatilization, and denitrification leading to N_2O emissions. Three soil C pools are used: fresh residue C, microbial biomass C (living and dead), and humus C (active and passive in terms of mineralization).

A crop growth module was developed to simulate total crop dry matter, leaf area index, root depth and density distribution, harvest index, crop yield and N uptake. Agricultural management practices including crop rotation, method of tillage, stubble return, irrigation and any additional fertilizers were inputs to the simulation. The process model was fully integrated into a GIS by using a uniform data structure, ARC GRID ASCII format, which can be f operated both in the GIS environment and in the process model.

Development of the ADST

The spatially-referenced ADST was developed by simulating a large number of management scenarios and identifying the BMPs according to selected criteria. The selected criteria were expressed in terms of crop yield, irrigation water use efficiency (IWUE), nitrogen fertilizer use efficiency (NFUE), nitrate leaching, N_2O emission and total regional water use for agriculture. Because the concept of alleviating over-exploitation of water resources was difficult to quantify, the indicator 'total regional water use for agriculture' was adopted instead.

Results and applications

Developing and calibrating the WNMM model

WNMM ran at a daily time step at different scales, driven by lumped variables (climatic data and crop biological data) in text data format, and spatial variables (soil and agricultural practices) in ARC GRID ASCII data format. Figure 1 shows examples of simulated and measured variables for the OHEP at Fengqiu. There was good agreement for soil water storage, leaf area index, and NH_3 volatilization between 1 October 1998 and 30 September 2000, a period which covered two winter wheat and summer maize growing seasons. However, the correlation between simulated and measured evapotranspiration (ET) was weaker, partly because of the difficulty of obtaining reliable measurements of actual ET from lysimetry and the Bowen ratio method.

Development and applications of a GIS-based ADST

A user-friendly ADST was developed by simulating a large number of scenarios and selecting BMPs based on the evaluation criteria described above. Nominal weighing factors were allocated to each of these criteria. The ESRI MapObjects GIS component was used to manage the relevant spatial databases. The ADST is a GIS-based map display tool with a number of search/query functions for seeking site-specific BMPs. The performance of the cropping system under BMPs was compared with current practices, as determined from an extensive farmer survey.

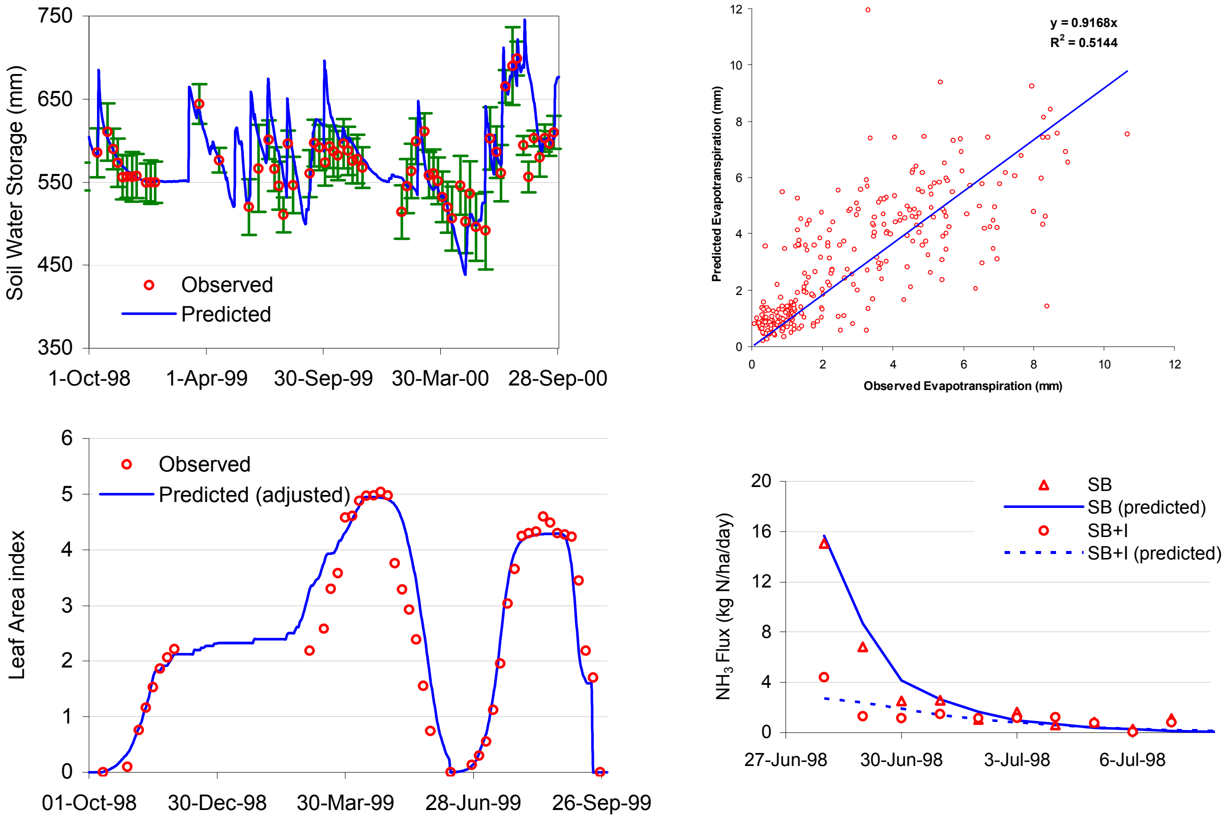

Figure 1. WNMM simulations and measured data of soil water storage (0-170 cm) (top left), actual ET (top right), leaf area index (bottom left), and NH_3 volatilization (bottom right) in the OHEP at Fengqiu County (SB denotes surface-broadcasting and SB+I surface-broadcasting immediately followed by irrigation) (Yong *et al.* 2007).

Applying BMPs identified by the ADST in Fengqiu County would result in a reduction of 115 kg /ha/year in fertilizer N (26% less than the average) and 150 mm/year of irrigation water (33% less than the average), while the average crop yield would be comparable to the current surveyed yield (Table 2). IWUE and FNUE would increase by 32% and 20%, respectively. Nitrate leaching and N_2O emission would be decreased by 60% and 25%, respectively. The potential reduction in irrigation water use would be 56 million m^3 for the whole county, which amounts to 13% of the total water used for agriculture. For an average sized farm, if recommendations on fertilizer use and irrigation were fully adopted, input costs would fall by 12-18% and income per household increase by 5%, equivalent to an increase in household income of AUD50-109 per year.

Table 2. Comparison of outcomes from current agricultural practices and BMPs provided by the ADST in Fengqiu County.

Indicators	Current practices	BMPs	
		Amount	Change (%)
Irrigation amount (mm)	450	300	-33%
Fertilizer amount (kg/ha)	450	335	-26%
Crop yield (kg/ha)	10300	10000	-3%
IWUE (kg/ha/mm)	25	33	32%
FNUE (kg/kg N)	25	30	20%
NO_3^- leaching (kg N/ha)	56	22	-60%
N_2O emission (kg N/ha)	24	18	-25%
Total in field water use for wheat-maize rotations (m^3 x 10^6)[A]	168	112	-33%

[A]The wheat-maize cropping area is 37,150 ha

Use of the ADST has facilitated the adoption of better management practices. The actual project benefit in the year of completion is summarized in Table 3, as reported by Harris (2004). The adoption rate for fertilizer advice was high at 55%, but adoption of irrigation advice was much lower at only 10%. About 95% of total project benefit comes from fertilizer savings and only 3% from water savings. The low adoption rate of irrigation advice is most likely due to the low water price in Fengqiu County, such that the cost of irrigation accounts for only 14%, while fertilizer accounts for up to 40%, of total input costs. The overall net benefits attributed to the project were estimated at AUD216 million (Harris 2004), which showed the significant poverty-reduction potential of the project.

Table 3. Project benefits in Fengqiu County by the year of completion, 2003-2004.

Cost saving per household after adoption	12-18%	Increase in income per household	5%
Adoption rate for fertilizer use	55%	Cost saving from fertilizer use (AUD million)	1.008
Adoption rate for irrigation	10%	Cost saving from irrigation (AUD million)	0.03
Total project benefit (AUD million)	1.04	Proportion of water saving in total county water use	13%

The change in benefit for crop yield was assumed to be zero

Conclusions and future directions

Both field measurements and WNMM simulations of water and N cycling showed excessive use of irrigation water and N fertilizer for wheat-maize rotations in Fengqiu County, NCP. Of the total N cycling in the soil-plant system, there was a surplus of about 20% in the soil after allowing for all the losses. Ammonia volatilization was the main pathway of N loss if fertilizer was surface broadcast. Nitrate leaching was as high as 82 kg N/ha/year, or 16% of the applied fertilizer. Denitrification loss was less significant in these light-textured soils, averaging 5% of applied N, of which 50% was lost as N_2O. BMPs derived from the ADST could reduce these losses with considerable cost savings. Catchment-based management is more appropriate than management based on local administrative units (villages and counties) and WNMM is being extended to a catchment scale by integration with a 3-D hydrological model. Climatic variability, particularly of rainfall, can also be incorporated into the ADST. A more comprehensive socio-economic component is being developed to take account of farmers' perceptions of the relative importance of farm productivity, profitability and environmental effects.

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China's food security threatened by soil degradation and biofuels production

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Abstract
We present a large scale assessment of the combined effects of soil degradation and biofuels production on long-term food security in China by using a web-based land evaluation system (http://weble.ugent.be) and grid datasets. Our results predict that the relationship between food supply and demand will turn from an 18% surplus in 2005 to 3-5%, 14-18% and 22-32% deficits by 2030-2050 under the zero-degradation (0xSD), business-as-usual (BAU) and double-degradation (2xSD) scenarios, respectively, if no harvests are to be diverted to produce biofuels, while this relationship will turn from a 17% surplus in 2005 to 14-17%, 22-32% and 30-46% deficits by 2030-2050, respectively, should 10-15% of the total harvests be used for biofuels production. Technical countermeasures and policy interventions (cropland protection, agricultural investment, soil conservation, etc.) need to be enacted today in order to avoid food insecurity tomorrow.

Key Words
Food security, soil erosion, biofuels production, scenario building, land evaluation, policy options.

Introduction
The global battle to ensure food security for humanity on earth is far from won (Borlaung 2007). As the world's most populous country and the third largest in size, China has succeeded in achieving food self-sufficiency in the past few decades. However, whether China will have the ability to produce enough food for a growing population which demands a richer diet in the twenty-first century remains a subject of debate with far-reaching impacts on the world food market (Anderson and Peng 1998). Whereas the effect of climate change on food security has received much attention recently (Lobell *et al.* 2008), much less attention has been paid to soil degradation as a major driver of global environmental change; systematic studies to link soil degradation and food security (Lal 2007) are still lacking, especially at the national scale. Moreover, as the world's third largest bio-ethanol producer, China used some 5 Mt of maize and wheat, or 1% of its total grain harvest, to produce 1.6 Mt of ethanol in 2005. The Chinese ethanol output is expected to increase under the new national energy stratagems (Li and Chan-Halbrendt 2009). Although this biofuel boom might help mitigate climate change, it could also threaten food security (Boddiger 2007). The objectives of this paper are to (1) simulate China's food security status by 2030 and 2050 in terms of a food security index (FSI); (2) quantify the FSI responses to soil degradation and biofuels production scenarios; and (3) formulate policy options in order to safeguard long-term food security in China.

Methods
A five-step approach has been adopted in this research. First, climatic, crop, soil, management and socio-economic data were collected, manipulated in a 5×5 km grid system and used to simulate the yields of food crops (i.e. rice, wheat, maize, sorghum, millet, soybean and potato) using a Web-based land evaluation system (WLES, http://weble.ugent.be; see Ye *et al.* 2008) which adopts a three-step, hierarchical, deterministic land evaluation model (Ye and Van Ranst 2002). Second, the simulated yields were compared to the observed yields in order to validate the simulation process. Third, the food production capacities in 2030 and 2050 were estimated based on the most-likely scenarios of population growth, urbanization rate, cropland area, cropping intensity, soil degradation and biofuels production. Fourth, a food security index (FSI) was computed following a food supply-demand equilibrium approach. Finally, the effects of soil degradation and biofuels production on FSI were quantitatively assessed, and policy options toward long-term food security in China were formulated (Figure 1).

The effect of soil degradation on crop yield was quantified in two steps. First, an overall score was computed from the extent and impact class of five common degradation types (i.e. water erosion, wind erosion, physical deterioration, fertility decline and salinisation) on crop yield (van Lynden and Oldeman 1997):

$$d = \sum_{i=1}^{5} \left(E_i \cdot I_i \right) \quad (1)$$

where d is the overall score, E_i is the extent of degradation type i, expressed as area percentage (%) within a mapping unit, and I_i is the code of the impact class (ranging from 0 for "negligible" to 4 for "extreme") of degradation type i. Second, the overall score was regrouped into 5 classes (Table 1) and each class was associated with a corresponding level of relative yield loss (Ye and Van Ranst 2009).

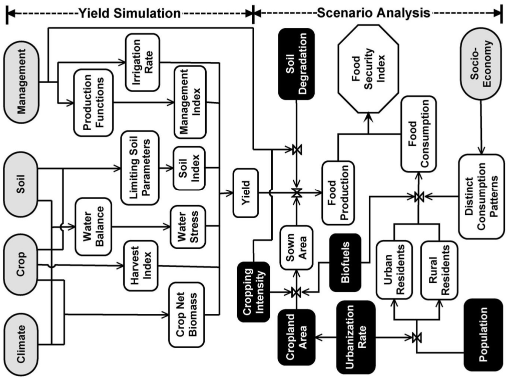

Figure 1. The research framework illustrating yield simulation and scenario analysis approaches.

Table 1. Yield effect of soil degradation expressed in relative yield loss (%).

Class of overall score d (Eq. 1)	Input level		
	High	Intermediate	Low
Negligible	0	0	10
Light	0	10	25
Moderate	10	25	50
Strong	25	50	75
Extreme	50	75	100

Table 2. The settings of the most-likely scenario for food production in China by 2030 and 2050.

Scenario	2005	2030	2050
Population (billion people)	1.31	1.46	1.44
Urbanization rate (%)	43	73	83
Cropland area (million ha)	130	113	107
Multi-cropping index (%)	120	133	147
Soil degradation (yield loss since 2005)			
Zero degradation	-	$0 \times p$ [a]	$0 \times p$
Business-as-usual	-	$1.67 \times p$	$3 \times p$
Double degradation	-	$3.33 \times p$	$6 \times p$
Biofuels production (million ton - Mt)			
Planned output	1.6	13	20
Estimated use of grain harvest	5.0	41	63

[a] p: relative yield loss (%) between 1990 and 2005 (Eq. 2).

The factor of soil degradation was incorporated into yield simulation using this equation:

$$Y_2 = \left(1 - n \cdot \frac{t_2 - t_1}{15} \cdot \frac{p}{100} \right) \cdot Y_1 \quad (2)$$

where Y_1 is the observed crop yield in year t_1, Y_2 is the average crop yield in year t_2, p is the fraction (%) of yield that is lost due to soil degradation during a 15-year period (van Lynden and Oldeman 1997) prior to year t_1, and n is a multiplicative coefficient. The product ($n \times p$) denotes the effective degradation rate during [t_1, t_2], compared to p during [t_1-15, t_2]. Under the business-as-usual (BAU) scenario, soil degradation occurred at the current intensity. The same amount of yield would be lost in the next 15 years as in the past 15 years, or $n = 1$. Under the zero-degradation scenario (0× SD), no degradation would occur ($n = 0$), whereas under the double-degradation scenario (2× SD), soil degradation would occur at twice the rate, limiting the crop yield more than at present ($n = 2$).

The relative food surplus in per capita terms was defined as the food security index (FSI):

$$FSI = \frac{(s-b)/g - d}{d} \cdot 100 \quad (3)$$

where s is the per capita supply, d is the per capita demand, b is the amount of food diverted to produce biofuels, and g is the expected food self-sufficiency level (g = 0.95).

China's food production capacities in 2030 and 2050 were assessed under the most-likely scenarios of cropland availability, cropping intensity, and soil degradation (Table 2). The FSI values for the years 2030 and 2050 were computed, after the distinctive food consumptive patterns of the urban and rural residents were characterized, involving additional scenarios (Table 2) including population growth, urbanization rate and biofuels production (see Figure 1).

Results

Comparison between simulated and observed yields in major regions

Crop production was simulated per grid cell and the simulated yield was aggregated to compute the average yield per major region in food production. The arithmetic mean was used as the aggregation algorithm since the area of each grid cell is equal. The difference between the predicted yield in 2030/2050 and the baseline yield in 2005, or yield loss, was obtained and summarized in Table 3 for the following regions in food production: the northeast (NE), the North China Plain (NCP), the lower Yangtze River Basin (YRB), and the Sichuan Basin (SB). In 2005, these major regions contributed over 70% of the total production of food from crops sown on 60% of China's croplands and supported 70% of China's population. An average grain yield of 4.85 t/ha was achieved in, e.g., the NCP in 2005. If the current trend of fertility decline and salinisation is not controlled, 6-10% of this yield will likely be lost by 2030-2050. The yield decrease would be as high as 10-18% by 2030-2050, should the situation continue to deteriorate (2× SD) in the NCP.

Table 3. Simulated versus observed yields of food crops in 2005 across major regions and simulated yields in 2030 and 2050 as compared to 2005 under the business-as-usual and double-degradation scenarios.

Region	Yield in 2005			Yield in 2030				Yield in 2050			
	Observed	Simulated	Error	Under BAU		Under 2× SD		Under BAU		Under 2× SD	
	t/ha	t/ha	%	t/ha	diff [a]	t/ha	diff	t/ha	diff	t/ha	diff
NE	4.61	4.64	+0.65	4.04	-12.93	3.74	-19.40	3.84	-17.24	3.04	-34.48
NCP	4.85	4.89	+0.82	4.59	-6.13	4.39	-10.22	4.39	-10.22	3.99	-18.40
YRB	5.23	5.21	-0.38	4.81	-7.68	4.61	-11.52	4.71	-9.60	4.11	-21.11
SB	4.77	4.52	-5.24	4.02	-11.06	3.62	-19.91	3.72	-17.70	3.02	-33.19
National	4.62	4.59	-0.64	4.09	-10.89	3.79	-17.43	3.89	-15.25	3.19	-30.50

[a] Percentage (%) difference of the yield as compared to 2005.

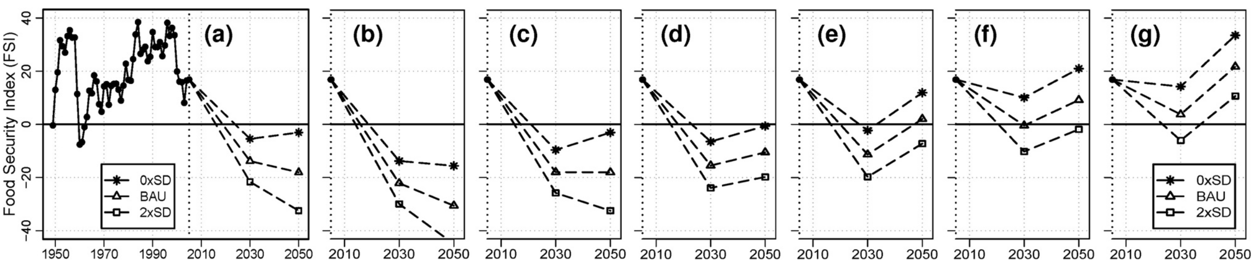

Figure 2. (a) Food security index as assessed on the basis of observed data during 1949-2005 and as predicted under the scenarios of zero degradation (0× SD), business-as-usual (BAU) and double degradation (2× SD) in 2030 and 2050. (b-c) FSI in 2030 and 2050 as affected by both soil degradation and biofuels production using first- or second-generation technologies. (b) Biofuels are derived from grain harvests. (c) Biofuels are derived from non-food crops, but 50% of such crops still compete with food crops for land in 2030. (d-e) Same as (b) and (c) but under a raised management scenario. Crop management level in middle China is raised to the same level as in east China. Crop management level in west China is raised to the level of middle China in 2030 and to the level of east China in 2050. (f-g) Same as (b) and (c) but under a high-yielding varieties scenario. Yields are steadily improved at an average rate of 0.8%/yr during 2005-2030 and 0.5%/yr during 2030-2050. Such yield improvements are only possible in areas under the high management level.

Food security index

Historical variations in China's food security status were well captured by the FSI values (Figure 2a). The results suggest that China faces great challenges in safeguarding its food security in the long run. The FSI is predicted to drop from 17 in 2005 to -5 and -3 in 2030 and 2050, respectively, under 0× SD (Figure 2a), exhibiting the adverse effect of population growth on food security. This suggests that the present-day (2005-level) production capacity will not sustain the long-term needs of the Chinese population, even under 0× SD. Our results also show that 14-18% and 22-32% of per capita demand will not be met by 2030-2050, under BAU and 2× SD, respectively (Figure 2a). This translates into an addition of 300-500 million malnourished people by 2050 to the 2005-level of 120 million. By 2030, some 41 Mt of maize and wheat could be diverted away from human consumption to the production of 13 Mt of bio-ethanol (Table 2). This diversion alone may drag the FSI down by 9 units (from -5 to -14) under 0× SD in 2030 (Figure 2b), showing that first-generation biofuels (which depend on food crops) have a strong adverse effect on food security. There are hopes that the full-scale development of second-generation biofuels (which are derived from non-food crops, e.g. wood chips and switch grasses, and require fewer water resources) could help reduce the impact of biofuels on food security (Figure 2c). However, such a solution is at least a decade away. Even with second-generation biofuels, the competition with food crops for land and water still remains if the growing of such second-generation crops is not on e.g. the abandoned land through delicate planning (Campbell *et al.* 2008).

Conclusion

The reproduction of the spatial variations in the observed yields of food crops by the simulated yields and the close reflection of the historical variations in food security in China since 1949 by the obtained FSI values show that the proposed research framework applied well in this large-scale assessment of the effects of soil degradation and biofuels production on long-term food security status in China. One of the major predictions made by this research is that soil degradation will become the most influencing factor that threatens China's food security in the long run. The food security status will further deteriorate if more grains are to be diverted away from human consumption to produce biofuels. Our simulation results strongly suggest that the present-day production capacity will not sustain the long-term needs of a growing population which demands a richer diet under the current management level. We advise the following policy interventions and institutional reforms: (1) Non-agricultural occupation of cropland should be strictly controlled. The abandoned land resources should be reutilized for biofuels production. The impact of second-generation biofuels is largely controllable if produced on abandoned land, as illustrated by comparing Figure 2c to 2a for year 2050. (2) Agricultural investments are essential to mitigate, or even to reverse, the impact of soil degradation on food security. Significantly positive responses of the FSI values have been predicted to either a higher management scenario (Figure 2d-e) or a higher-yielding varieties scenario (Figure 2f-g). (3) Institutional changes in, e.g., the selection and extension of a locally suitable soil and water conservation techniques pool are needed to control the environmental damages caused by production intensification. Otherwise, the improvements in food security (Figure 2d-g) will not be sustainable in the long run.

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Enhanced efficiency fertilizers

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Abstract
World food security is challenged by many issues, including weather and climate variability, degraded soils and persistent poverty. To address these problems, we must look for solutions to reduce the delivered cost of agricultural inputs-especially fertilizer-that improve stakeholder returns and promote agricultural intensification. Improving fertilizer use efficiency by reducing nutrient losses is a critical step towards increasing soil fertility and agricultural productivity for poor farmers. This paper presents results from both field and greenhouse studies that illustrate the use of improved management practices, such as fertigation and deep placement of nitrogen (N) and phosphorus (P), and use of innovative new modified fertilizers that increase nutrient use efficiency (NUE). The results show how the controlled delivery of nutrients, where nutrient delivery is synchronized to crop demand, creates opportunities to increase yields and improve NUE.

Key Words
Enhanced efficiency fertilizers, nutrient use efficiency, deep placement, controlled-release.

Introduction
World population growth, increasing demand for food, water shortages, soil losses, environmental issues and weather uncertainty are among the many challenges that threaten food security in many regions of the world. An estimated 1.5 billion people, or a quarter of the global population, depend directly on land that is being degraded (FAO 2009). Twice as many people around the world are subsisting on less than US $2 a day amidst strained natural resources. Almost 33% of people in Sub-Saharan Africa (SSA) and 17% in Asia are undernourished. In Asia, the main challenge remains how to maintain steady growth in crop yields in the face of diminishing marginal returns to agricultural inputs. In SSA, the main challenge is how to reduce the delivered cost of inputs so that farm intensification becomes economically preferable to opening new land. The high cost of agricultural inputs, especially fertilizer, adds to the growing concern about having enough food for people around the world. The farm-gate cost of fertilizer is higher for farmers in SSA than in Asia partly due to higher transportation costs (Chemonics 2007). Farmers can improve their net returns from agriculture with lower cost inputs and/or enhanced efficiency of input use. Reducing nutrient losses is a critical step towards improving soil fertility and agricultural productivity for poor farmers. It makes sense from every perspective-agronomic, economic and environmental. The low nutrient absorption rate of 30%-40% by crops for applied N, P and potassium (K) fertilizers is inefficient and must be improved. For example, by improving N use efficiency 15%-20%, the projected food production increase for 2030 can be obtained with 20 million tons less fertilizer than based on the current average fertilizer N recovery of 35% (Daberkow *et al.* 2000). Improved management practices, products and crop attributes all lead to increased nutrient use efficiency. The integrated use of mineral fertilizers and recycled waste products not only reduces the amount of fertilizer applied but further improves nutrient and water use efficiency. The key to both improving efficiency of applied nutrients and reducing losses is the synchronization of the nutrient delivery from soils, biological nitrogen fixation, organic materials and mineral fertilizers with the crop requirements (Singh 2005). The paper will present results from field and greenhouse studies illustrating the use of improved management practices, such as fertigation and deep placement of N and P, and use of new and innovative products that increase nutrient use efficiency.

Methodology
Improved management practices
Deep placement of fertilizers, particularly urea, has resulted in improved yields and lower N and P losses from flooded rice fields (Kapoor *et al.* 2008; Bowen *et al.* 2005). Fertilizer deep placement (FDP) involves placing 1- to 3-gram briquettes of urea, urea + diammonium phosphate (DAP), or urea + DAP + potassium chloride at 7-10 cm soil depth shortly after transplanting rice. The technology addresses the challenges of low productivity in rice ecologies by increasing nitrogen use efficiency and reducing P runoff losses. Deep placement of urea eliminates nitrogen losses due to volatilization, denitrification and floodwater run-off,

allowing farmers to realize a 30% increase in yields over the same nitrogen when conventionally applied (Bowen *et al.* 2005). Deep placement also ensures N availability beyond the flowering stage due to reduced early tillering and more available N, encourages algal biological nitrogen fixation because of low floodwater N concentration and reduces weed competition (Singh 2005).

Fertilizer deep placement trials were conducted in Nangarhar, Afghanistan, with conventional and conservation tillage practices in 2008. The impact of improved versus local rice variety was also evaluated. A survey study that included 3,230 rice-growing households, distributed through 80 upazilas and 14 districts in Bangladesh, was conducted during the 2008 Boro season. Paddy yields, labor requirements and production costs were compared for deep placement versus conventional urea application (Thompson and Sanabria, 2009). Greenhouse and field trials were conducted to expand deep placement to upland vegetable crops. The greenhouse study was conducted in Muscle Shoals, Alabama, U.S.A., and the field trials were in collaboration with the Bangladesh Agricultural Research Institute in Jodhpur, Bangladesh.

Innovative N products

The innovative N products evaluated under laboratory, greenhouse and field conditions were designed to control or modify the delivery of N to synchronize with plant N demand. The improvement in efficiency of these products was achieved through the following mechanisms:

(1) Urease inhibition,
(2) Nitrification inhibition,
(3) Modifying soil rhizosphere, and
(4) Controlled- or slow- release of nutrients due to solubility of product, type of coating or mineralization of product.

Field trials with controlled-release fertilizers under rainfed and irrigated conditions using the simple Chapin bucket drip kit system were conducted at Bujumbura in Burundi, Ashaiman in Ghana and Kigali in Rwanda during 2008. Additional tests with modified products, including fertilizers made using municipal wastewater residuals (Reimers and Weber 2008), were conducted at IFDC's laboratories and greenhouse in Muscle Shoals, Alabama.

Results

Improved management practices

The rice grain yields from the Afghanistan study were significantly higher with FDP than with broadcast application of urea using the leaf color chart (LCC) for side-dressing of N with conventional tillage (Figure 1). Under zero-tillage, rice grain yield was significantly higher for the Kunduz rice variety. The on-farm survey in Bangladesh showed that the average yield on farms using FDP was significantly higher than the yields with broadcast application of urea in all 14 districts. Yield increases due to FDP between 100-3,000 kg/ha occurred in all upazilas and in 62 of 80 upazillas, yield increases were 1,000-1,700 kg/ha. The expansion of FDP to upland crops was evaluated in the greenhouse (Figure 2) and under field conditions. In Bangladesh, upland crops including tomatoes, cabbages and eggplants gave very favorable returns to farmers with FDP (Table 1).

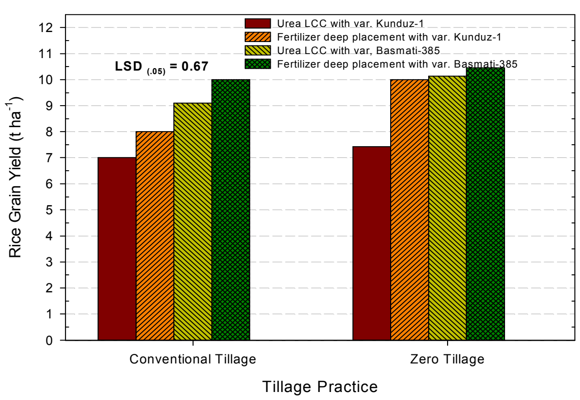

Figure 1. Effect of fertilizer deep placement on grain yield of lowland rice.

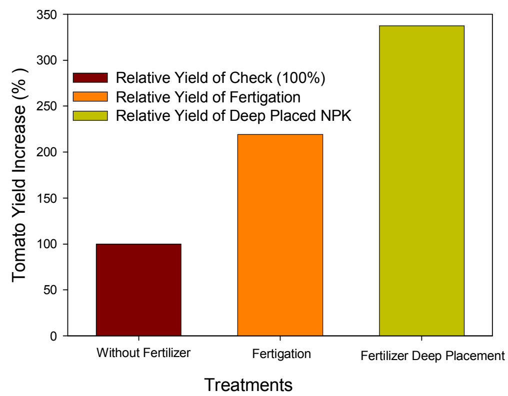

Figure 2. Comparison of tomato yields with fertigation and fertilizer deep placement.

Table 1. Economic benefits of fertilizer deep placement due to yield increase and N saving on eggplants in Bangladesh.

Urea quantity (kg/ha)	Yield (t/ha)	Money (Taka/ha)			Increase over recommended dose	
		Gross income	Cost of cultivation	Net profit	Yield (%)	Taka/ha
320-broadcast urea	26.97	228,420	61,163	167,257	-	-
320-FDP	35.16	300,930	62,897	238,033	31	70,776
288-10% less FDP	32.39	279,210	62,175	217,035	20	49,778
256-20% less FDP	28.56	249,330	61,525	187,805	6	20,548

Innovative N products

The inhibition of urease and nitrification activity, and thus lower N losses due to volatilization and leaching, were dependent on soil properties and the efficacy of the modified fertilizers. In general, the urease inhibitor, NBPTP, significantly reduced volatilization losses on a wide range of soils (Figure 3). Application of a nitrification inhibitor (dicyandiamide [DCD]) and use of DCD containing fertilizers such as AgrotainPlus delayed nitrate formation and hence could improve NUE by reducing nitrate leaching and denitrification losses (Figure 4).

Combined biosolids-inorganic fertilizer showed significant reduction in volatilization loss-2% and 21% of applied fertilizer N compared with 33% and 57% with urea under upland and flooded conditions, respectively. Leaching losses were also significantly lower for biosolid-inorganic fertilizer, 4%-13% compared with 41%-86% of applied fertilizer N with urea. These results also translated into higher grain yields for rice, wheat and vegetables. Up to 30% higher yields were obtained with controlled-release fertilizers with okra, cabbage and sweet pepper in Ghana, Burundi and Rwanda.

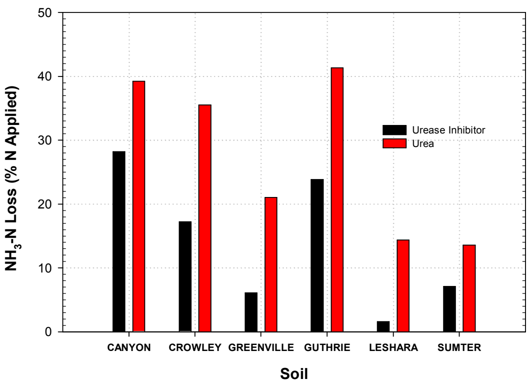

Figure 3. Cumulative ammonia volatilization loss after 17 days under flooded condition.

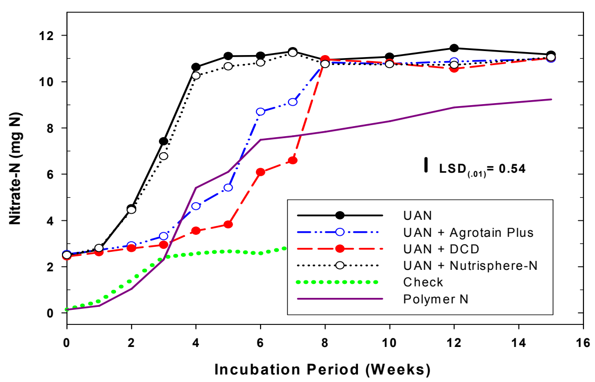

Figure 4. Nitrate formation after adding nitrification inhibitor (DCD) to urea ammonium nitrate (UAN) compared to nitrate release from polymer N fertilizer.

Conclusions

There are opportunities to increase yields and improve NUE by using enhanced efficiency fertilizer products and improved management practices. Innovative technologies enable farmers to minimize risks by controlled delivery of nutrients, deep "point placement" of nutrients and by the use of decision support tools for improved crop recovery of nutrients. Fertilizer research to develop enhanced efficiency fertilizers at lower costs for smallholder farmers in the developing world is an ongoing activity of IFDC and collaborating partners.

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Growing sugarcane for bioenergy – effects on the soil

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Abstract
An increasing area of sugarcane is being growing for the production of bioenergy. Sugarcane puts a high demands on the soil due to the use of heavy machinery and because large amounts of nutrients are removed with the harvest. Biocides and inorganic fertilizers introduces risks of groundwater contamination, eutrophication of surface waters, soil pollution and acidification. This paper reviews the effect of commercial sugarcane production on soil chemical, physical and biological properties using data from the main producing areas. Although variation is considerable, soil organic C decreased in most soils under sugarcane and, also, soil acidification is common as a result of the use of N fertilizers. Increased bulk densities, lower water infiltration rates and lower aggregate stability occur in mechanized systems. There is some evidence for high leaching losses of fertilizer nutrients as well as herbicides and pesticides. Eutrophication of surface waters occurs in high-input systems. Sugarcane cultivation can substantially contribute to the supply of renewable energy, but that improved crop husbandry and precision farming principles are needed to sustain and improve the resource base on which production depends.

Introduction
Sugarcane as a biofuel crop has much expanded in the past decade, yielding anhydrous ethanol (gasoline additive) and hydrated ethanol by fermentation and distillation of sugarcane juice and molasses. Byproducts are bagasse and vinasse (stillage or dunder) which is the liquid waste sometimes used for fertigation purposes. Bagasse, a by-product of both sugar and ethanol production, can be burned to generate electricity or be used for the production of biodegradable plastic. It provides most of the fuel for steam and electricity for sugar mills in Australia and Brazil. One ha of sugarcane land with a yield of 82 t/ha produces about 7,000 L of ethanol. Brazil currently produces about 31% of the global production and it is the largest producer, consumer, and exporter of ethanol for fuel (Andrietta *et al.* 2007). Between 1990 and 2005, global average sugarcane yields increased from 61 to 65 Mg/ha (http://faostat.fao.org). In some countries sugarcane is the main source of revenue and in Mauritius sugarcane occupies 90% of the arable land (Ng Kee Kwong *et al.* 1999). Globally, the area harvested increased by 2.6 million ha in the period 1990-2005; the largest expansion was in India and Brazil. It is expected that the area under sugarcane in Brazil will expand by 3 million ha over the next five years whereas the area under sugarcane in China is forecast to rise by 5% or more than 100,000 ha/y. Traditionally, sugarcane was harvested manually; the senescent leaves (trash) and stalks were removed by people using big knives. In the past two decades, pre-harvest burning has been replaced by mechanical green- or trash-harvesting by cutter-chopper-loader harvesters that leave the trash on the field. Irrigation and large amounts of inorganic fertilizers are often required for high yields. As a consequence, soil properties are likely to change under sugarcane cultivation and the high biocide inputs may affect the environment. Environmental concerns and policies are key factors affecting the future of sugarcane production. There is a also risk that the sugar industry is expanding on marginal lands where the costs or preventing or repairing environmental damage may be high. This paper reviews the main soil and environmental issues under continuous sugarcane cultivation. Most of this work pre-dates the surge of sugarcane production for bioethanol but the results are very relevant for the new situation.

Data Sources and Types
There is fair a body of literature on changes in soil properties under sugarcane cultivation (Table 1). Changes in soil properties under continuous sugarcane have been investigated in two ways. Firstly, soil properties are monitored over time at the same site (Type I data). In the second approach, soils under adjacent different land-use systems are sampled at the same time (Type II data).

Discussion and conclusions
Sugarcane is an ideal crop for renewable energy because of its rapid growth and high energy production per ha. Fossil energy is needed for growing of the crop and the production of bioethanol, which partly offsets the energy produced. In Brazil, fossil energy costs are minimized by use of processing products like bagasse for energy. The energy balance (yield over fossil energy) of such systems may range from 9 to 11

Table 1. Studies focusing on changes in soil chemical, physical and biological properties under sugarcane cultivation.

Soil order	Country	Soil property investigated			Data[A]	
		Chemical	Physical	Biological	Type I	Type II
Alfisols	Australia	✓	✓	✓		✓
	Brazil	✓	✓			✓
	India	✓				✓
	Swaziland	✓	✓	✓		✓
Andosols	USA Hawaii	✓		✓		✓
Fluvents	Australia	✓	✓	✓		✓
	Brazil	✓				✓
	Fiji		✓			✓
	USA Hawaii		✓			✓
	Iran		✓			✓
	Mexico	✓				✓
	Papua New Guinea	✓	✓		✓	✓
Inceptisols	Australia	✓		✓		✓
	India	✓	✓	✓		✓
	Iran		✓			✓
	South Africa	✓	✓			
						✓
Oxisols	Brazil	✓	✓	✓		✓
	Fiji	✓	✓		✓	
	USA Hawaii		✓			✓
	South Africa	✓	✓	✓		✓
	Swaziland	✓	✓	✓		✓
Spodosols	Australia		✓	✓		✓
	USA	✓				✓
Ultisols	Australia			✓		✓
	Brazil		✓			✓
	Indonesia	✓			✓	
Vertisols	Mexico	✓	✓			✓
	Papua New Guinea	✓	✓		✓	✓
	South Africa	✓	✓	✓		✓
	Zimbabwe	✓		✓		✓
not specified	Australia	✓	✓	✓		✓
	India	✓	✓			✓
	Mexico	✓				✓
	Philippines	✓			✓	
	South Africa	✓	✓			✓
	Trinidad		✓			✓

[A]Type I are data whereby soil dynamics are followed with time on the same site; Type II are data whereby different land-use was sampled simultaneously – see Hartemink (2006)

(Macedo 1998), which compares very favorably to many other biofuel crops. In part, this favorable balance is explained by the relatively low N application rates to sugarcane in Brazil, because of the high rates of biological nitrogen fixation. In many agricultural systems, inorganic fertilizers are a major budget line. Overall, biological nitrogen fixation can be considered one of the principal reasons for the success of the bioethanol program in Brazil (Medeiros *et al.* 2006). Most studies have shown that soil acidification takes place under sugarcane, principally due to the use of N fertilizers containing or producing NH_4^+. All ammoniacal N fertilizers release protons when NH_4^+ is oxidized to NO_3^- by nitrifying micro-organisms. Also, mineralisation of organic matter can contribute to soil acidity by the oxidation of N and S to HNO_3 and H_2SO_4 (Sumner 1997). Since organic matter declined in most soils under sugarcane, it may have contributed to the increase in soil acidity. Acidity is reversible; liming readily restores productivity but if acidification has also taken place in the subsoil, amelioration is much more difficult. There is only a small response of sugarcane to lime on moderately acid soils (Turner *et al.* 1992) whereas in other studies a decrease in the sugar content was found after lime applications (Kingston *et al.* 1996). Sugarcane is fairly tolerant of acidity and high concentrations of exchangeable and soluble Al (Hetherington *et al.* 1988); avoiding strong soil acidification might be a better option than the use of lime to correct for high acidity inputs.

Soil organic C dynamics have received much attention in sugarcane, but there are some conflicting reports. Part of the problem is that total soil organic C determined by the Walkley & Black or the dry combustion method is not very sensitive to short-term changes in land-use. Long-term observations are required to pick up statistically significant differences in soil organic C levels. It is also related to the spatial variability in total soil organic C. Notwithstanding these methodological problems, total soil organic C decreased in most topsoils and in most soil types. This may be the effect of tillage which causes increased soil organic matter decomposition compared to soils under natural ecosystems, but, also, because of lower inputs of organic matter in sugarcane systems. Soil texture plays an important role in the rate of change in soil organic C and this change also differs for different size fractions. An equilibrium is reached after many years, but it is generally lower than the initial level in the soil under forest. In a number of soils, it was found that levels of soil organic C increased in the subsoil. The decrease in soil organic matter under continuous sugarcane reduces soil biological activity and increases the susceptibility of the soils to physical degradation.
Soil compaction is a common problem in mechanized systems, mainly due to the heavy machinery used for field operations at the wrong soil moisture levels. Erosion losses up to 505 Mg soil ha^{-1}/y have been reported under sugarcane. Erosion can be high after the harvest and with replanting, especially on sloping land (Blackburn 1984).

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Growth indices of eleven sugarcane varieties grown under full irrigation environments in Brazil

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Abstract
Growth analysis is considered a standard method for measuring the biological productivity of plant species in determined environmental conditions. The objective of this study was to evaluate growth and dry matter production in the planted cane cycle of eleven varieties of sugarcane (SP79-1011, RB813804, RB863129, RB872552, RB943365, RB72454, RB763710, SP78-4764, SP81-3250, RB867515, RB92579), cultivated under full irrigation. The experiment was installed in field conditions in Carpina county, PE, Brazil. A randomized block statistical design was used, with four replications. Growth analysis of the varieties consisted of height and diameter measurement of the stalks, evaluated monthly, in eleven periods of the cultivation that extended from 60 to 360 days after planting (DAP). Dry matter production in the above ground part was quantified from 120 until 360 DAP, with sampling intervals of every two months. At 360 DAP the varieties RB72454, RB92579 and RB867515 obtained the highest stalk height, while the varieties RB863129, RB72454 and RB867515 presented the greatest diameter values. However the greatest dry matter in above ground productions at 360 DAP was observed in the varieties RB92579, SP81-3250 and RB872552.

Key Words
Saccharum spp, height, diameter, dry matter.

Introduction
Sugarcane growth occurs through the interaction of the crop with environmental factors. The best comprehension of such interactions may be obtained by means of quantitative analysis of growth and by biometric measurements of the plants during their development, thus permitting the use of physiological indices in the attempt to verify the differences among varieties and model growth on different management and production environments. (Keating *et al.* 1999; Machado *et al.* 1982). The present study had the objective of evaluating growth and dry matter production in the above ground part during the planted cane cycle in eleven varieties of sugarcane cultivated under full irrigation

Material and methods
Site description
The study was at the Sugarcane Experimental Station of Carpina (EECAC/UFRPE), located in the State of Pernambuco, Brazil. The experimental area is situated in Carpina county, latitude 7º51'133''S and longitude 35º14'102''W in a soil classified as Arenic Ultisoil. Research was performed in the planted cane cycle during the 2006/2007 agricultural season, with registration of annual rainfall in this period of 1.732 mm and average temperatures greater than 25oC.

Experimental design
The experiment was conducted in a randomized block experimental design with four replications. Eleven varieties of sugarcane were evaluated, with five being of early maturity (SP79-1011, RB813804, RB863129, RB872552 and RB943365) and six of medium to late maturity (RB72454, RB763710, SP78-4764, SP81-3250, RB867515 and RB92579).

Water balance
The study was conducted under full irrigation until 300 days after planting (DAP), the replacement water was calculated based in the crop evapotranspiration (ETc) up to 0.6 m of depth. For this purpose, the results of water field capacity (WFC) and water permanent wilting point (WPWP) of the soil to a respective depth were taken into consideration, as well as the precipitation and the efficiency of the irrigation system used.

The water replaced took into consideration the crop water consumption estimated by the Equation: $Etc = ECA \times Kc \times Kp$, in which: ETc = crop evapotranspiration (mm); ECA = Class A pan evaporation (mm); Kc = crop coefficient; Kp = Class A pan coefficient (Inman-Bamber and McGlinchey, 2003).

Sampling

For growth evaluation, ten cane plants in the three central rows of each experimental plot were identified and stalk height and diameter data was collected monthly. Stalk height was measured from the soil level up to the dewlap (+1) and the stalk diameter was measured on the middle third of the plant. The leaf (+1) was considered as that which presented the first clearly visible dewlap. The dry matter production in the above ground was evaluated at 120, 180, 240, 300 and 360 DAP, collecting eight samples from the sugarcane in each experimental plot. The samples were divided up into tops, leaves and stalk, later being weighed, chopped in a forage chopper and subsampled. The subsamples were dried in a forced air circulation laboratory oven at 65ºC until reaching a constant weight and moisture was determined. With the moisture values and tillering (sugarcane per meter), dry matter accumulation in kg/ha was calculated.

Statistical analysis

The growth and dry matter data were submitted to analysis of variance in randomized block design, using the F test at $p<0,05$. For the significant variables, regressions were adjusted in relation to the period of growth and accumulation of dry matter for each variety evaluated. As criteria for the choice of regression models, models were selected that presented the greatest coefficient of determination and significance of the regression parameters up to 5% probability by the t test.

Results and discussion

Sugarcane growth in reference to stalk height obtained logistical adjustment (Table 1), characterizing three phases of development (Figure 1 A and B). The first phase of growth was similar for all the varieties studied, with a small increase in stature being observed up until 60 DAP, with mean values of 18 cm. In the second phase of growth, which occurred between 60 and 240 DAP, differences among the varieties and the greatest growth rates were seen, with mean values of 1.5 cm/dia. At the end of the second phase of growth, the early maturity varieties RB872552 and RB863129 obtained the greatest heights with values of 305 and 282 cm respectively (Figure 1 A). For the medium to late maturity varieties, RB867515, RB763710 and RB92579 presented the greatest growth in stalk length, with values of 306, 298 and 287 cm respectively (Figure 1B). In the third phase of growth, the varieties obtained mean gains of 49 cm, which represented 15 % of the total stalk height. In this phase, the greatest final growth was observed in the varieties RB72454, RB92579, RB867515, with values greater than 350 cm, while the variety SP79-1011 presented the lowest values of growth, with an estimated mean of 268 cm (Figure 1 A and B).

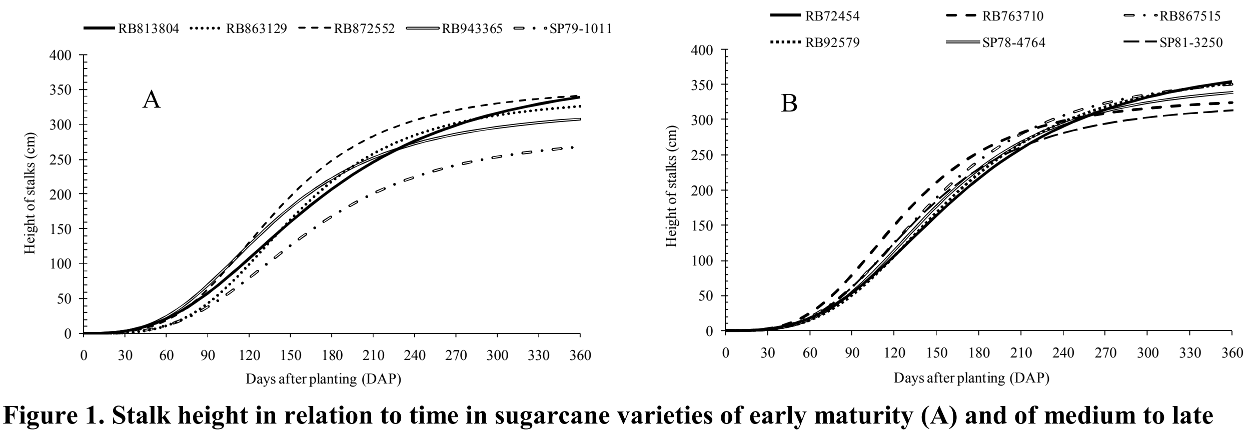

Figure 1. Stalk height in relation to time in sugarcane varieties of early maturity (A) and of medium to late maturity (B).

The first and second phase of growth were responsible for 85% of the total sugar cane stalk height among the varieties studied; in other words, the first two growth phases occurred from the months of October to June, a period characterized by low precipitation, greater light intensity and more elevated temperatures, which, when associated with water availability promoted by full irrigation, resulted in mean gains of 280 cm in stalk height. In the central south region of Brazil, Oliveira *et al.* (2004) in non-irrigated varieties observed the greatest gains in stalk height from the months of December to March, with mean growth rates of 1.7 cm/dia, making for final stalk statures of 326 cm, similar values to those observed in this study.

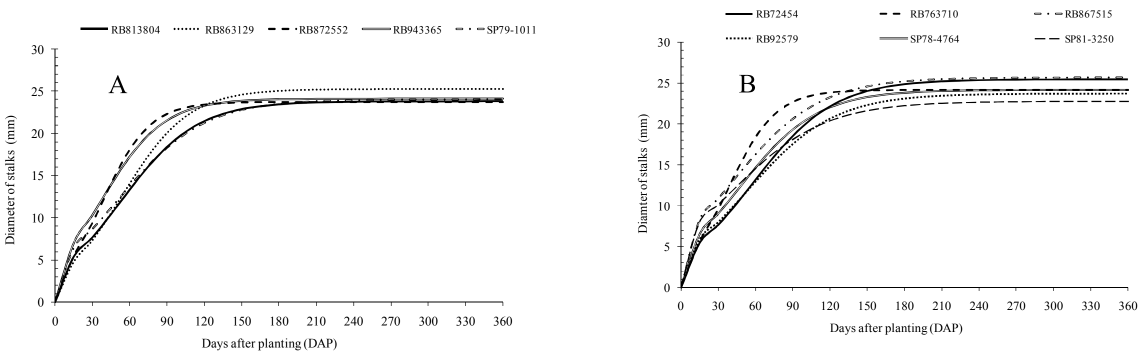

Figure 2. Stalk diameter in relation to time in sugar cane varieties with early maturity (A) and with medium to late maturity (B).

In relation to stalk diameter, the data was adjusted to the sigmoid model (Table 1), characterizing two phases of development (Figure 2 A and B). In the first phase, the increase in stalk diameter was rapid and constant, presenting a mean of 18 cm at the end of the period. The initial growth in stalk diameter differed among the varieties, In the varieties RB763710, RB867515, RB863129, RB872552 and RB913365, it was observed that the first phase continued up to 60 DAP and in RB72454, RB92579, SP78-4764, SP81-3250, RB813804 and SP79-1011, up to 90 DAP (Figures 2A and B). In the second phase, the sugarcane stalk diameter presented a small increase, obtaining mean values of 24 mm. Among the varieties, RB863129 of early maturity, and RB72454 and RB867515 of medium to late maturity presented the greatest diameters at 360 DAP, with a mean value of 26 mm respectively (Figures 2A and B).

The results for dry matter production in the above ground also differed among the varieties evaluated and, as observed for stalk height, the data obtained logistical adjustment (Table 1), which characterized three phases of accumulation of dry matter (Figure 3 A and B). The first phase occurred up to 90 DAP for all the varieties, except in RB943365 and RB813804, which presented the end of this phase at 60 and 120 DAP respectively. In this phase, mean accumulations in the above ground part of 8 Mg/ha were observed, with the medium to late maturity variety RB763710 and the early maturity variety RB943365 standing out, which accumulated 16 and 10 Mg/ha respectively in the first periods of development. In the second phase of growth, accumulation of dry matter was more intense and presented different periods among the varieties, making for the formation of three distinct groups. The first group, formed by the varieties RB763710 and RB867515, obtained accumulations of 52 Mg/ha from the end of the first phase up to 210 DAP. The varieties RB72454, SP78-4764, RB943365 and SP79-1011 presented the lowest accumulations in the second phase, with mean gains of 41 Mg/ha up to 240 DAP being observed. The third group, formed by the varieties RB92579, SP81-3250, RB813804, RB863129 and RB872552 presented the second period of development in the interval from 90 to 300 DAP, with mean accumulations of 56 Mg/ha. It was observed that this phase represented, for the three groups of varieties formed, 73, 65 and 74% respectively of the total accumulated shoot dry matter.

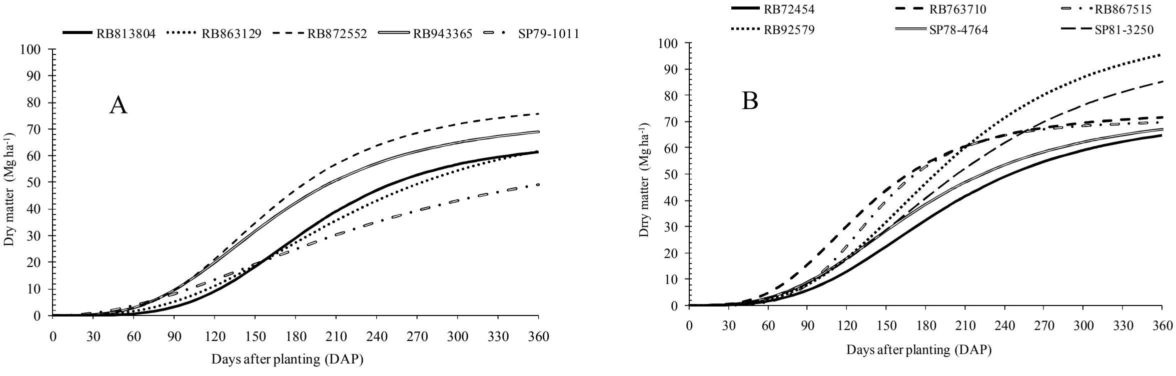

Figure 3. Accumulated shoot dry matter in relation to time in sugar cane varieties with early maturity (A) and with medium to late maturity (B).

In the third phase, the early maturity variety RB872552 stood out from the rest, with final accumulations of 76 Mg/ha of dry matter (Figure 3A). In the medium to late maturity varieties, the greatest accumulations were obtained by RB92579 and SP81-3250, with production of 96 and 85 Mg/ha of dry matter in the above ground respectively. These results give evidence of the high response of these varieties to full irrigation management in the edafoclimatic conditions of the Brazilian northeast. The results of dry matter production obtained corroborate with those found by Almeida *et al.* (2008), who also observed in the variety RB92579 the greatest accumulations of dry matter, but with a yield of 30 t/ha less than that observed in this study. The smallest responses to full irrigation were seen among the varieties RB72454, SP78-4764, RB813804, RB863129 and SP79-1011 with shoot accumulations of 65, 67, 61, 61 and 49 Mg/ha respectively (Figure 3 A and B).

Table 1. Equations adjusted for stalk height, stalk diameter and shoot dry matter in relation to time in sugar cane varieties with early maturity and with medium to late maturity (* significant to p < 0,01).

Varieties of early maturity			
	Hight	Diameter	Dry matter
RB813804	$Y= 382,3/[1+(DAP/169,2)^{-2,7293}]$; $R^2 = 0,97^*$	$Y= 23,84/[1+ exp^{\{-(DAP-52,69)/30,46\}}]$; $R^2 = 0,90^*$	$Y= 66,38/[1+(DAP/191,8)^{-3,9276}]$; $R^2 = 0,94^*$
RB863129	$Y= 341,0/[1+(DAP/153,6)^{-3,6176}]$; $R^2 = 0,97^*$	$Y= 25,24/[1+ exp^{\{-(DAP-53,98)/26,70\}}]$; $R^2 = 0,85^*$	$Y= 75,82/[1+(DAP/219,0)^{-2,9341}]$; $R^2 = 0,95^*$
RB872552	$Y= 354,1/[1+(DAP/140,7)^{-3,4223}]$; $R^2 = 0,97^*$	$Y= 23,74/[1+ exp^{\{-(DAP-38,03)/18,90\}}]$; $R^2 = 0,85^*$	$Y= 80,68/[1+(DAP/163,2)^{-3,3995}]$; $R^2 = 0,95^*$
RB943365	$Y= 325,2/[1+(DAP/139,2)^{-2,9968}]$; $R^2 = 0,96^*$	$Y= 24,11/[1+ exp^{\{-(DAP-37,27)/24,79\}}]$; $R^2 = 0,80^*$	$Y= 75,00/[1+(DAP/165,9)^{-3,1381}]$; $R^2 = 0,96^*$
SP79-1011	$Y= 288,6/[1+(DAP/162,3)^{-3,1994}]$; $R^2 = 0,96^*$	$Y= 24,07/[1+ exp^{\{-(DAP-49,99)/34,53\}}]$; $R^2 = 0,82^*$	$Y= 70,81/[1+(DAP/242,0)^{-2,0634}]$; $R^2 = 0,98^*$
Varieties of medium to late maturity			
RB72454	$Y= 391,4/[1+(DAP/167,5)^{-2,9509}]$; $R^2 = 0,97^*$	$Y= 25,46/[1+ exp^{\{-(DAP-57,70)/32,75\}}]$; $R^2 = 0,84^*$	$Y= 73,72/[1+(DAP/193,6)^{-3,2163}]$; $R^2 = 0,93^*$
RB763710	$Y= 334,8/[1+(DAP/127,7)^{-3,3379}]$; $R^2 = 0,97^*$	$Y= 24,17/[1+ exp^{\{-(DAP-37,97)/19,05\}}]$; $R^2 = 0,83^*$	$Y= 74,33/[1+(DAP/134,3)^{-3,3258}]$; $R^2 = 0,86^*$
RB867515	$Y= 370,5/[1+(DAP/148,1)^{-2,2120}]$; $R^2 = 0,97^*$	$Y= 25,74/[1+ exp^{\{-(DAP-40,83)/34,99\}}]$; $R^2 = 0,82^*$	$Y= 70,81/[1+(DAP/141,6)^{-4,5326}]$; $R^2 = 0,92^*$
RB92579	$Y= 377,5/[1+(DAP/160,5)^{-323,21}]$; $R^2 = 0,96^*$	$Y= 23,70/[1+ exp^{\{-(DAP-53,61)/34,83\}}]$; $R^2 = 0,84^*$	$Y= 109,05/[1+(DAP/196,8)^{-3,2584}]$; $R^2 = 0,95^*$
SP78-4764	$Y= 357,5/[1+(DAP/151,0)^{-3,3094}]$; $R^2 = 0,98^*$	$Y= 24,19/[1+ exp^{\{-(DAP-46,47)/31,59\}}]$; $R^2 = 0,87^*$	$Y= 75,23/[1+(DAP/177,1)^{-2,9753}]$; $R^2 = 0,98^*$
SP81-3250	$Y= 326,5/[1+(DAP/138,5)^{-3,3460}]$; $R^2 = 0,96^*$	$Y= 22,76/[1+ exp^{\{-(DAP-38,46)/38,03\}}]$; $R^2 = 0,81^*$	$Y= 102,25/[1+(DAP/207,2)^{-2,9149}]$; $R^2 = 0,88^*$

Conclusion

Stalk growth and dry matter accumulation differed among the varieties analyzed. The varieties more responsive to management with full irrigation, when associated with climate and soil conditions as observed in this study, intensified plant development in relation to traditional cultivation without irrigation. Thus, varieties like RB872552, RB92579 and SP81-3250 which are responsive to irrigation, become an important tool in varietal management and in the profitability of the sugarcane fields located in regions that have an elevated water shortage for most of the crop season.

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Incorporating groundnut into the maize-based smallholder farming systems in semi-arid Limpopo province, RSA

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Abstract
Incorporation of grain legumes into existing predominantly maize-based monoculture smallholder farming system may improve the productivity and sustainability of the system. This paper presents the results of a study conducted on-farm with the aim of evaluating the best groundnut cultivar for incorporation into the existing predominantly continuous maize cropping system. Treatments consisted of three groundnut (*Arachis hypogaea*) cultivars (Kwarts, Akwa and Kangwana red) and four phosphorus fertilizer rates (0, 15, 30 and 60 kg P/ha applied as superphosphate at planting) arranged in a completely randomized block design with three replications. Dry matter was measured at regular intervals and grain yield determined at maturity. The APSIM model was used to simulate growth and grain yield. Cultivar and P application had no effect on grain yield. Grain yield ranged from 554 to 649 and 1254 to 1503 kg/ha, in 2007/8 and 2008/9 seasons, respectively. A strong relationship (R^2=0.83) was recorded between observed and simulated grain yield. Long-term simulation with non-limiting P indicated that 50% of the seasons yielded >506 kg/ha grain. Low rainfall coupled with prolonged drought periods during growing season may have limited the potential response to P application.

Key Words
Groundnut, phosphorus, APSIM model, smallholder farmers, South Africa.

Introduction
Farming under smallholder systems in Limpopo province is characterized by a low level of production and small farm sizes of approximately 1.5 ha. The majority of these smallholder farms are located on infertile soils with any production primarily used for subsistence and little marketable surplus. An increasing pressure on the land resources is due population growth and has resulted in continuous cultivation and depletion of plant nutrients. Very few farmers can afford to purchase inorganic fertilizers due to their limited resources. Sole unfertilized maize is the dominant cropping system in this region. Legume intensification is often advocated to improve the productivity and sustainability of cereal based cropping systems in developing countries (Snapp *et al.* 1998). These technologies include agro-forestry systems, green manures, and legume intercrops or rotations. Experimentation has shown that these systems can enhance soil productivity through biological nitrogen fixation, carbon inputs and conservation of nutrients (Snapp *et al.* 1998). This paper presents the results of a study conducted on-farm with the aim of evaluating the best groundnut cultivar for incorporation into the existing predominantly continuous maize cropping system. The objectives of this study were to: (i) assess the effect of cultivar and phosphorus fertilizer application on grain yield of three groundnut cultivars over 2 seasons; and (ii) validate the performance of the APSIM model (Keating *et al.* 2003) to simulate the growth and yield of groundnut.

Materials and methods
A group of smallholder farmers from Bloodriver (23.817896°, 29.370232° 1244 m asl) near Polokwane in Limpopo Province South Africa had formed the Perkesbult Farmer Association and were experimenting with various grain legume options. At this location, a researcher managed field experiment was established in two seasons 2007/08 and 2008/09 (separate sites in each season) to evaluate three groundnut (*Arachis hypogaea*) cultivars (Kwarts, Akwa and Kangwana red) and four phosphorus fertilizer rates (0, 15, 30 and 60 kg P /ha applied as superphosphate at planting). The experiment was laid out as a complete randomized block design with three replications. Individual plot sizes measured 3 m x 3 m and seeds were planted at a spacing of 0.3 m x 0.6 m, to give a target population of 55556 plants/ha. Planting took place on 3 Jan 2008 and 18 Dec 2008. Data such as emergence, dry matter at 6-8 weeks after planting and flowering, grain yield at maturity were collected. Measured data was analyzed using SAS software. The APSIM model was used to

simulate grain yield production with soil being characterized according to the procedures of Dalgleish and Foale (1998) and the groundnut model parameterized according to Robertson *et al.* (2001). Existing groundnut cultivars available in APSIM were adjusted to match the phonological stages measured in the field experiments. To assess the goodness of fit of the simulations to measured data, the root mean square error (RMSE) between predicted and observed data was calculated as:

$$RMSE = [(\sum (O - P)^2/n)]^{0.5}$$

where O and P are the paired observed and predicted data and n is the number of observations.

Results and discussion

Crop production at this site is severely limited by low soil fertility, low soil water holding capacity and highly variable rainfall. Despite these limitations, smallholder farmers attempt to grow food crops such as maize, sorghum and a range of grain legumes, although crop failures are common and yield is usually low. The soil on which the experiments were located was a highly erodible coarse sand derived from granite (Plinthic soil with high base status), with a rooting depth of about 60cm and a plant available water capacity (PAWC) of 72 mm. Chemical fertility and carbon content is low (Table 1). According to weather records from Polokwane (about 20 km away) average annual rainfall is 475 mm with growing season rainfall (November to March) of 370 mm.

Table 1. Some soil physical and chemical properties of the soil at the experimental site.

pH	Sand	Silt	Clay	N	C	K	Ca	Mg	P
(H_2O)	------------%--------------			%	%	---------cmol(+)/kg--------			mg/kg
5.95	82.3	5.7	12	0.017	0.37	0.234	0.98	0.756	2.0

During the growing period, a total amount of 135 and 252 mm of rainfall was received in the 2007/8 and 2008/9 seasons, respectively. This resulted in grain yield ranging from 554 to 649 kg/ha in 2007/08 and 1254 to 1563 kg/ha in 2008/09 with no significant differences found between the cultivars or P application rates (Table 2).

Table 2. Effect of cultivar and P application rates on grain yield (kg/ha) of three groundnut cultivars in 2007/8 and 2008/9 seasons.

Factor	Grain yield (kg/ha)	
	2007/8 Season	2008/9 Season
Cultivar		
Kwarts	554a	1254a
Akwa	649a	1344a
Kangwana	567a	1563a
Phosphorus rate (kg/ha)		
0	507a	1112a
15	610a	1497a
30	621a	1615a
60	623a	1323a
F-test probabilities		
Cultivar	ns	ns
Phosphorus rate	ns	ns
Interaction (CxP)	ns	ns

Within Columns, means followed by the same letter are not significantly different at $P \leq 0.05$.

The observed and simulated grain yield at 60 kg P/ha in 2007/8 and 2008/9 seasons fall within the observed variation (RMSE = 168) (Figure 1). The linear regression between simulated and observed grain yield in 2007/8 and 2008/9 seasons when P is non-limiting had R^2 value of 83%, indicating a positive strong relationship (Figure 1). Crop production in this environment is highly risky due to low inherent soil fertility, low soil water holding capacity and highly variable rainfall. In simulations of maize growth without fertiliser N (1960-2009), it was found that there was complete crop failure in 60% of seasons (data not presented). This decreased to 30% of seasons with the application of 15 kg/ha of N fertiliser, but average grain yield remained below 1000 kg/ha. While growing grain legumes such as groundnuts results in >80% of seasons resulting in a successful crop, yield remains <506 kg/ha in 50% of seasons (Figure 2).

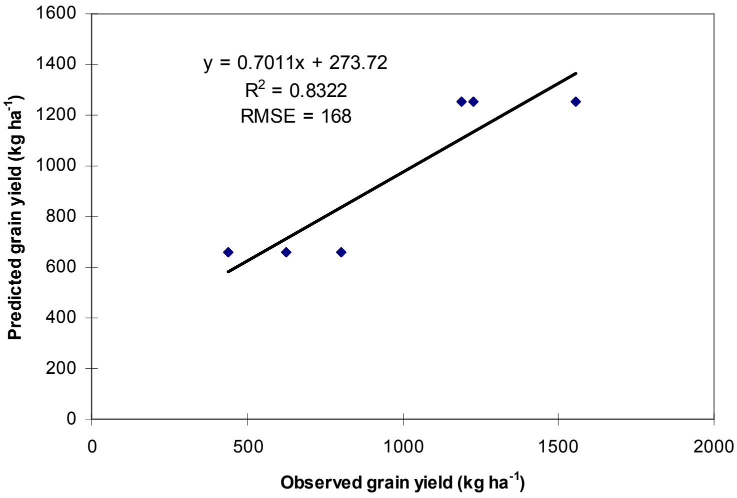

Figure 1. The relationship between the observed and predicted grain yield for 2007/8 and 2008/9 seasons at 60 kg/ha.

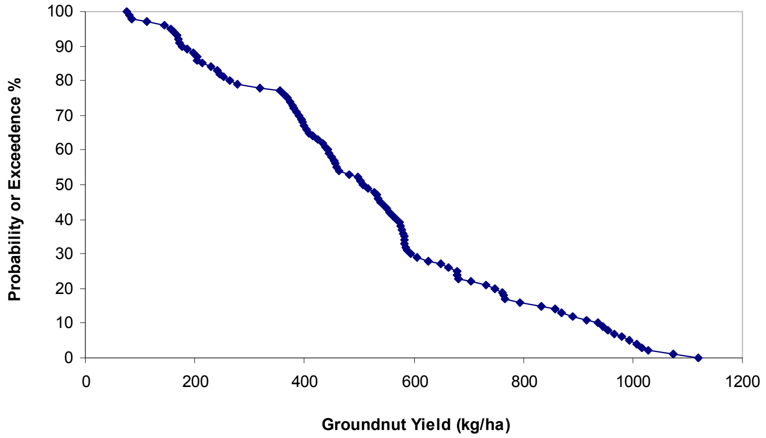

Figure 2. Long-term simulation (1961-2009) for grain yield with cultivar Kangwana when P is non-limiting.

Conclusion

Low rainfall, coupled with prolonged drought periods during the growing season may have limited the potential for response to P application. Cultivars Akwa and Kangwana are promising and may have the potential to produce better grain yield if there is sufficient rainfall. The APSIM model was able to simulate grain yield production with a fairly good degree of precision.

Acknowledgement

This study is part of a larger collaborative study being conducted by scientists from CSIRO, Australia and various research organizations, institutions and stakeholders in the agricultural sector in Limpopo province of South Africa, and is funded by ACIAR.

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Intercropping of sugarcane with common bean in no-tillage and different nitrogen rates

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Abstract

The no-tillage of crop rotation and intercropping are sustainable practices to reduce the impact of sugarcane to produce bioethanol on food safety. The objective of this research was to study the effect of side dressing nitrogen application on dry bean (IAC-Alvorada) grown as intercropped crop with green harvested sugarcane ratoon in no-tillage, named "*sweet common bean system*". Field experiment was carried out in a commercial area (Oxisol), at Sao Jose Farm (Sertãozinho, Sao Paulo State, Brazil), planted with genotype RB865536, on the 3rd ratoon. Five treatments of side dressing nitrogen rates (0, 40, 80, 120, and 160 kg/ha of N, as Urea) were arranged in a complete randomized block, with 6 replications. Evaluations (dry matter, LAI) were done from 30 to 90 days after planting (DAS). A quadratic response was observed for dry biomass and grain yield, with 120 and 80 kg/ha, respectively the best N-rate. LAI increasing with N-rates until the maximum of 5.5 at 75 DAS IAC-Alvorada can be considered responsive (12.8 kg of grains per kg of N) to increasing N-rates.

Key Words

Conservation tillage, *Phaseolus vulgaris*, *Saccharum officinarum*, food and biofuel.

Introduction

In recent years, the demand for bioethanol production is rapidly increasing worldwide, and in many countries, debates have already started concerning the competition for land use between energy and food crops. According to Lal (2009), the projected global energy demand will increase a rate of 2.23% per year by 2025; therefore it is extremely important adoption of sustainable production systems, such as the no-tillage, which is practiced only on 6.4% of world's cropland. Brazil has had a long time tradition in the use of renewable energy and is the second largest area under no-till farming (more than 40% of cropland). In some parts of Brazil, previous areas of grain crops are now cultivated with sugarcane, which is grown on more than 8.2 million of hectares. The widespread adoption of no-tillage soybean on sugarcane straw has achieved tremendous success in enhancing soil quality, preventing soil erosion, and weed control (Christoffoleti *et al.* 2007, Bolonhezi 2008). However, the practice of crop rotation with leguminous crop (estimated to be 1 million hectares available every year) is only possible after 5 or 6 ratoons of sugar cane. Intercropping of sugarcane with grain crops, is one possibility to associate energy and food production and has been used in commercial fields since the late 1960's, especially with common bean (Tokeshi 1980; Govinden 1991). In Sao Paulo State, annually there are accessible more than 600 thousand hectares of sugarcane with irrigation, which it would be possible to grow common bean with sugarcane, during the winter. Common bean (*Phaseolus vulgaris* L.) is one of the most important sources of plant protein for a large part of the world population and nitrogen is a main constituent. Nowadays, there are available modern no-tillage planters, which may provide suitable planting under sugarcane straw (average 15 Mg/ha of dry matter biomass). Nevertheless, it is important to point out that, in this condition, the recommended N rate (from 30 to 60 kg/ha of N) can be insufficient to supply the requirement of this crop. In this context, we hypothesize that growth of common bean between sugarcane ratoon rows is feasible, but it is necessary to increase the nitrogen rate in no-tillage systems. The aim of this research was to evaluate different levels of side dressed N in no-tillage on grain yield, leaf area index, and macronutrients content all long of several growth stages of common bean.

Materials and Methods

Location, Soil characteristics and Experimental Design

The trial was carried out in a commercial sugarcane area situated at São José Farm, in Sertãozinho city, São Paulo State, Brazil. Chemical attributes of the Dark Red Latosol are presented in the Table 1. The experiment was set up in a green harvested sugarcane field of the RB865536 on the 3rd ratoon. The amount of dry biomass on the soil surface was estimated at 20 Mg/ha. Approximately 30 days after harvesting the sugarcane, two rows of the common bean cv. IAC-Alvorada (erect growth habit and maturity range around 92 days after planting) were sown (08/14/2008) between sugarcane rows. Five treatments of side dressed nitrogen rates (0, 40, 80, 120, and 160 kg/ha of N, as Urea) were arranged in a complete randomized block, with 6 replications. Each plot contained 4 rows of bean spaced 0,5 m and with 8 m of length, divided per one (1) row of sugarcane. A planter model COP-CA® (Tatu Marchesan), was used which has special cutter disk. Fertilization was done according to recommendations of Ambrosano *et al.* (1996), and consisted of 10, 50 and 50 kg/ha of N, P_2O_5 and K_2O. The side-dress N-rates were applied in 09/05/2008. Irrigation was done using a water-spraying system, from sowing (08/14/2008) to the peak of flowering (10/15/2008).

Table 1. Chemical properties of surface and subsurface soil (0.0-0.20 and 0.20-0.40 m). Sao Jose Farm, Sertaozinho city, Sao Paulo State, Brazil.

Depth (m)	pH	O.M.	P (resin.)	K	Ca	Mg	S	CTC	V
	$CaCl_2$	g/dm	mg/dm	--------------mmol$_c$/dm-------					%
0-0.20	5.9	23	30	1.8	53	10	18	86	76
0.20-0.40	5.5	21	47	2.3	46	8	20	82	69

Evaluations

Plant samples were taken every 15 days, from emergence to harvest. Each sample was composed by aboveground biomass collected in 1 meter of row. Simultaneously, Leaf Area Index (LAI) data collection was performed using indirect measurements with a LAI-2000. In each replication were evaluated 3 different points. This aboveground biomass was oven-dried at 65^o C, weighed and ground to determine the concentration of macronutrients (N, P, K, Ca, Mg, and S) at the Soil Research Centre of Agronomic Institute of Campinas according to Bataglia (1993). Pods were harvested (4 rows with 5 meters in each plot) 90 days after planting and the grain yield was expressed in kg/ha. Data were subjected to ANOVA and regression analysis.

Results

Concerning effects of nitrogen rates on plant dry matter yields, a significant increase was observed at 45 and 60 days after sowing (DAS), and the data fitted a quadratic regression equation (Figure 1). The highest dry matter of aboveground biomass, was observed with the N-rate of 120 kg/ha, while Silva *et al.* (2004) reported that in no-tillage the highest dry biomass was obtained with the N-rate of 75 and 100 kg/ha. High levels of nitrogen are important in no-tillage on sugarcane straw, because there are large amounts of residue on the soil surface (high N-immobilization by microorganisms) and due to the competition with sugarcane plant for nutrients and water. In Figure 2, shows the variation of LAI from 30 to 90 days after planting for each N-rate. The difference increase until 60 days after sowing and practically disappeared at the last evaluation. The highest LAI (5.4) was measured at 55 days after sowing, for N-rate of 160 kg/ha, which was 2 times higher than the control. Pavani *et al*. (2009) observed the maximum LAI (4.4) in no-tillage at 69 days after sowing. The high LAI in the control at 75 days after sowing, could be explained by the BNF (Biological Nitrogen Fixation) or nitrogen stock in the soil. According to Luca *et al.* (2008) after three harvests of sugarcane, the decomposition of accumulated aerial residue biomass (40 t/ha) could release up to 0.022 t/ha of nitrogen. Moreover it is important to consider that the N_2 fixation is stimulated under great amount of straw, as well as the mineral N can be deleterious to nodulation (Cardoso *et al*. 2007). Even though, there were significant differences in the N-concentration at the first evaluation, no significant variations were found in the second and third evaluations. However, the amount of nitrogen extracted by aboveground biomass was significantly lower in the control. At the first evaluation, the response was linear and at second and third evaluations, the responses were quadratic, with the highest extraction at the N-rate of 120 kg/ha. This result is important because farmers need to reduce the cost of nitrogen (in average 100 kg/haof N) applied in the sugarcane ratoon, given that the residue of IAC-Alvorada can return to the soil after harvest, at least 30 kg/ha of nitrogen. Nevertheless, Araujo *et al.* (2009) mentioned that some genotypes were more efficient than others based on harvest index, which is the dry matter of the pods divided by the total dry matter. The quadratic effect was observed for grain yield (Figure 4) and the highest yield was obtained with the N-rate of 80 kg/ha. These results agree with research carried out by Silva *et al*. (2004) and Junior *et al*. (2009), both in no-tillage systems. An increase of 12,8 kg/ha grain was observed per kg/ha of nitrogen used. The cultivar IAC-Alvorada could be considered a responsive genotype, according to Araujo *et al.* (2009).Overall, the results emphasize that intercropping of bean and sugarcane ratoon was viable because, it can use the same area to produce food and energy, can reduce the application of herbicide, can supply part of the nitrogen requirement of sugarcane, and can improve the profit of farmers. Therefore, this system could be named "*sweet common bean*", due to the success of this first attempt. In future researche it would be important to study the residual effect of nitrogen applied on the stalk yield of sugarcane.

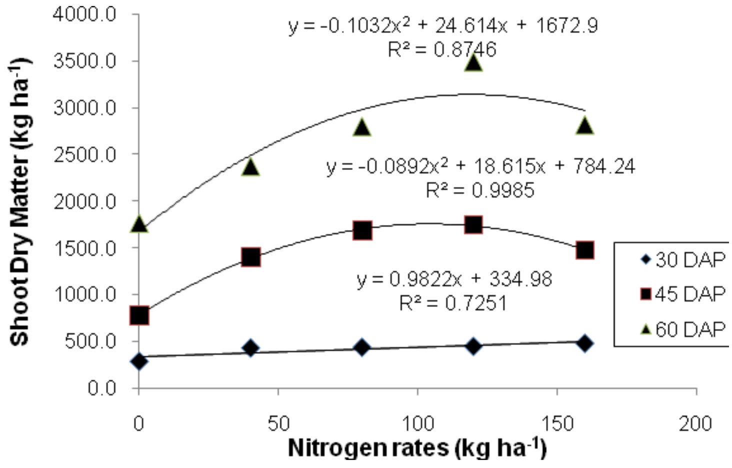

Figure 1. Variation of shoot dry matter of cv. IAC-Alvorada, with increasing nitrogen rates.

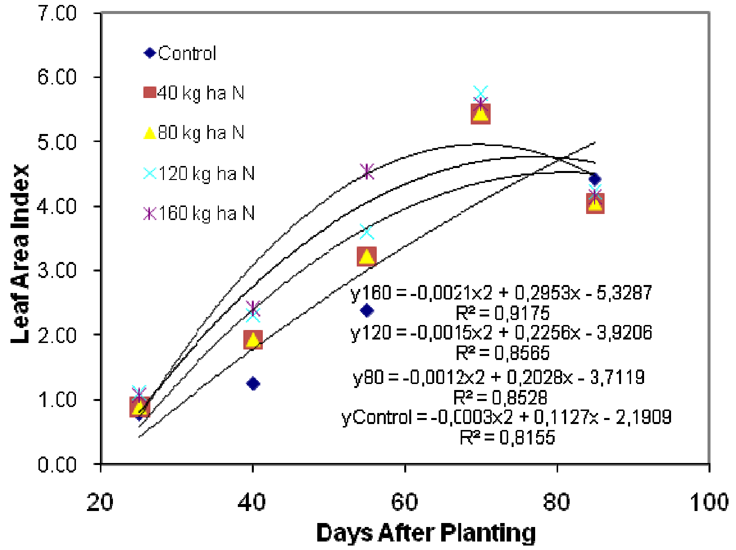

Figure 2. Leaf area index in different growth stages and nitrogen rates.

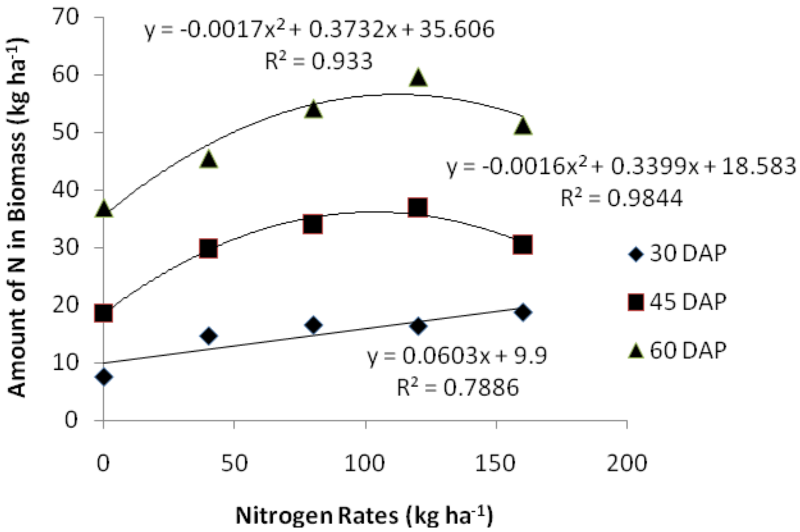

Figure 3. Extraction of nitrogen in the biomass of common bean cv. IAC-Alvorada.

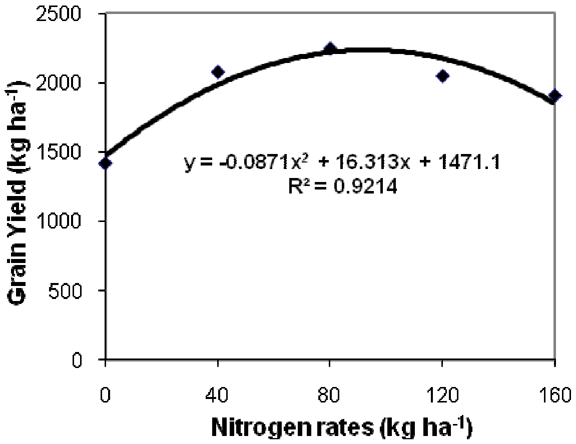

Figure 4. Grain yield of common bean cv. IAC-Alvorada grown with sugarcane for several N-rates .

Conclusion

At 45 and 60 DAS, the highest dry biomass and amount of nitrogen extracted were for the N-rate of 120 kg/ha. The LAI increased with increasing N-rate until the maximum of 5.5 at 75 DAS. A quadratic response was verified for grain yield with the highest (2244 kg/ha) at the N-rate of 80 kg/ha. The cultivar IAC-Alvorada can be considered responsive (12.8 kg of grain per kg of N) to increasing N-rates.

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Peak phosphorus – Implications for soil productivity and global food security

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Abstract
Phosphorus is a key element in food production, but is a non-renewable resource. Recent estimates suggest that global production of P fertilizers will peak in 2033 and will be one third of that peak level by the end of the 21st century. Population and income growth will increase demand for food, and especially animal protein, the production of which will accelerate the reduced availability of P and consequential rising fertilizer prices. The global distribution of current P fertilizer use divides countries into the 'haves' which in many cases face severe pollution problems from excess P, and the 'have-nots' in which low input use annually drains soil P reserves. Coping strategies include improvements in the efficiency of fertilizer P manufacture and use, and recycling of P in liquid and solid wastes. The latter approach offers win-win solutions by reducing the environmental pollution of water in highly populated areas. Future utilisation of scarce P reserves requires policy decisions that take account of equity, productivity, environmental and trade considerations.

Key Words
Phosphate fertilizer, food production, trade, pollution, recycling.

Introduction
The 20th Century saw massive increases in food production that generally kept pace with a global population increase from 1.6 billion to 6 billion. Some of the production increase was due to opening new land for cultivation, but the green revolution in the high-potential areas, particularly in Asia, contributed significantly in the countries with major population growth. During that century, as modern fertilizer-responsive rice, maize and wheat became widely available, use of P fertilizers increased 3.5-fold (Tilman1999). In sub-Saharan Africa the 20th century saw declines in per capita food production and very limited use of fertilizers (Vlek 1990). In Latin America large areas of land in the Cerrados were opened to agriculture only after adequate fertility management using liming and P application was developed. P fertilizers also played a key role in agricultural production gains made in North America and Australia.
As one of the three major essential elements for plant growth, P supplies have and will continue to assert significant influence on efforts to expand food production. Importantly, plants concentrate P in the grains and fruiting bodies, which when harvested create a significant drain of P reserves in soil, so high yielding systems require P inputs at a minimum level that replaces harvest losses; unlike nitrogen, which can be fixed from the atmosphere, P is mined from limited deposits. Furthermore, to the extent that energy-intensive industrial N fixation can be replaced by biological nitrogen fixation by legumes, that process requires adequate P supplies.

Bruinsma (2009) estimated that to feed a projected population of 9 billion in 2050 will require a 66% increase in crop production from the base level in 2005/2007, while during the same period meat production will have to increase 85%. The latter projection is high because it takes account of increased incomes, particularly in the more populous countries of Asia. Demand for P fertilizers will therefore accelerate as the quantity and quality of food and feed grain production increases. However, P is a non-renewable resource with finite reserves; recent concerns about the future availability of P fertilizers (Cordell *et al.* 2009) have presented this as a major global challenge.

This paper reviews the global distribution of P use, transfers between regions, rates of soil P depletion and prospects for improving the P fertilizer efficiency and P re-cycling, in the context of peak P production.

P resources, use, balances and transfers
P resources
Annual global production of P rock in 2008 was 167 million tons, with China, the USA and Morocco and Western Sahara as the main producers (Table 1). Global reserves total 15,000 million tons but the country

rankings in terms of reserves are not the same as for annual production – the data for the USA indicate an annual rate of use of 19% of global production with only 7-8 % of the worlds' reserves. On the other hand, China's production is proportional to its reserves. Morocco and Western Sahara are conservative in their P extraction, as are minor producers such as Jordan and South Africa.

Table 1. Production of P rock and reserves in main producing countries (Jasinski 2009).

	Proportion of global total P rock (%)		
Country	2008 annual production	Reserves	Reserve base[1]
China	30	28	21
United States	19	8	7
Morocco/Western Sahara	17	38	45
Russia	7	1	2
Tunisia	5	<1	1
Brazil	4	2	<1
Jordan	3	6	4
South Africa	1	10	5
Global total P rock (Mt)	167	15,000	47,000

[1] Reserve base: P rock with a 'reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics'

A simple calculation (reserves divided by annual extraction rate) of the life of the P rock reserves at current rates of global production results in a 90 year lifespan for the USGS-classified reserves plus 281 years for the 'reserve base' (see Table 1 footnote for the definition). The calculation of future rates of production and peak P requires an understanding of the future rate of increase in demand, market price movements, and potential improvements in technology, especially to remove impurities economically. Cordell *et al*. (2009) have recently prepared a Hubbert curve that suggests a peak in P production of 29 Mt P/year in 2033. The rate of production reduces to 10 Mt P/ year in 2100. World trade issues, price rises over time that make deposits more economic to mine, and market forces will influence the life of P resources. A critical factor that is already changing markets and distorting availability is cadmium legislation. For example, a Finnish proposal to pass on new EU limits, would render no longer importable much of North African P, as long as cadmium removal remains an expensive proposition. P being a finite resource, there will be a peak. Needed more detailed studies of the issue are in progress, but current evidence suggests that peak P will become a reality and a serious problem facing the next two human generations.

P resources

The evidence reviewed above shows that P reserves are being utilised at an unsustainable rate. While the distribution of P rock reserves across countries of the world is uneven, the rate of use of the P is also extremely uneven. Figure 1 shows the 2005 annual consumption of P as fertilizer broken down by region, as well as projections to the year 2030, which is approximately when Cordell *et al.* (2009) expect P production to peak. Note that the global total consumption in 2030 that Tenkorang and Lowenburg-DeBoer (2009) project is 23 Mt of P, whereas Cordell *et al.*'s projection of peak production is 29 Mt. The highest level of P consumption in 2005, and projected to 2030, is in Asia, which reflects the high population as well as the intensive cropping systems, based on the use of irrigation and modern high-yielding varieties. Europe, North America and Latin America utilise proportionally less fertilizer, but the most striking contrast is the low consumption of P in Sub-Saharan Africa, and the low trajectory of the projected future use.

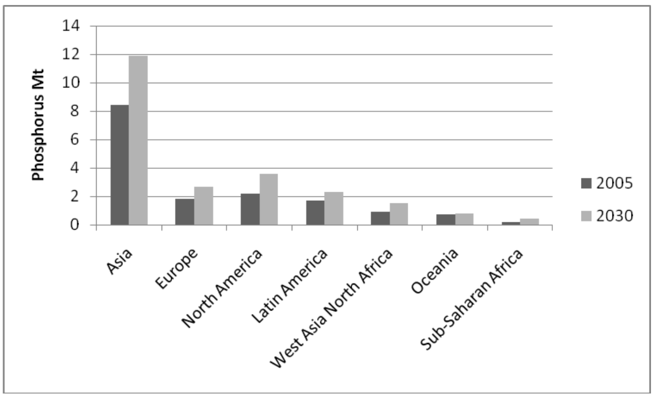

Figure 1. The annual consumption of P fertilizer in different world regions in 2005 and projections to 2030. Adapted from Tenkorang and Lowenburg-DeBoer (2009).

P balances

The low rate of fertilizer use is Sub-Saharan Africa is well documented (Batiano *et al*. 2006). Twenty five years ago, Vlek (1993) raised concern about nutrient exports from sub-Saharan Africa. In 2007, the export of stimulant crops alone removes around 50,000 tons of P from this region or one-fifth of the annual P use. This amounts to a doubling in P exports against a stagnant use of P fertilizer over the past 20 years. Over 30 years of repeated harvests without matching fertilizer applications has resulted in an estimated depletion of 75 Kg P/ha from 200 million ha of cultivated land in 37 African countries. This estimate is consistent with the figure of 3.3 kg P/ha/yr published by Sheldrick and Lingard (2004), who projected a rise in depletion rates to 6 kg P/ha/yr in 2020 unless rates of growth of fertilizer P use increased to 7% per year. There is a clear case for urgent action to address this problem, particularly viewed against a background of peak P. Fortunately some countries of Sub-Saharan Africa have native deposits of P rock that could be developed locally for direct application to help solve the problem if the fertilizer sector develops.

At the other end of the scale are 'nutrient surplus' countries (Craswell *et al.* 2004) in Western Europe, such as Belgium, Denmark, and the Netherlands, which import feed grains for livestock production creating a surplus of nutrients in the environment, and therefore face serious pollution problems. The same applies to some of the intensive production systems in North America and Asia. Excess P use can cause eutrophication of waterways and toxic algal growth that can cause red tides in coastal zones. This is a key area for environmental policy action, including international agreements; Bach and Frede (1998) report progress in reducing P surpluses in agricultural land in Germany by 60% in the last decade of the 20th century. In Australia, low rates of P over extended pasture and crop areas have led to neutral or slightly positive P balances. In Latin America P balances are generally positive for cash and plantation crops but negative in low yield subsistence cropping areas.

P transfers

The transfer of P and other nutrients in agricultural commodities in international trade is an area of increasing interest (Craswell *et al*. 2004), because like 'virtual water' trade it provides insights into whether particular countries should choose to grow their own food or import it (Grote *et al*. 2006). In many cases grounds for such a decision may be dominated by water availability but the consequences in terms of P flows are real, not virtual, and will become more important as P resources decline. The Figure 2 shows the positive and negative balances of P in traded agricultural commodities projected to 2020. Major food exporting countries and regions, especially the Americas, have large P deficits whereas importers are positive. Interestingly sub-Saharan Africa has a positive P balance due to food imports. Since these imports are largely consumed in cities, the opportunity for the use of P in municipal and animal wastes to improve peri-urban agriculture has been advocated by Cofie *et al.* (2001). The same applies to large cities in other regions such as Bangkok where Faerge *et al*. (2001) showed that only 10% of P is recovered and recycled whereas, of the P losses, 41% could be accounted for by elevated levels in the Chao Phraya River.

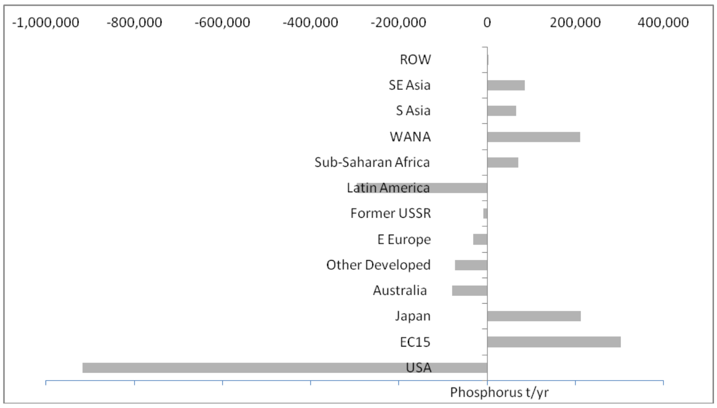

Figure 2. Projected regional flows of P in net trade of agricultural commodities in 2020. (Craswell *et al.* 2004)

Conclusion

The need for global action to address the need to increase agricultural production while finite P resources continue to decline is clear. Technological and policy options should be explored to form the basis for coping strategies. At the P production level, research is needed to improve the efficiency of processing in P fertilizer manufacture, including minimally heated P rock treatments (A. Roy, personal communication 2009.) Furthermore, the revision of market regulations for the water soluble P content of fertilizers will become more important as reserves decline. In the P-rich countries and regions, including hotspots, such as intensive animal production systems or urban and peri-urban areas, the emphasis should be on recycling which has the win-win advantage of also reducing environmental pollution. In crop production systems in both high and low potential areas, the efficiency of P fertilizer use should be improved through better timing and placement of P, as well as research on the improvement of P uptake by innovations such as inoculation with VA mycorrhiza.

Policy measures are needed that ensure a more equitable global P balance in which measures require both developed and developing countries to take action (Grote *et al.* 2005). In this context the wisdom of P investment in soils that have other major production constraints (semi-arid Africa for instance) will have to be judged against equity considerations. Furthermore such alternatives need to be assessed against the use of high P seeds for "renewable" energy production. Also important was recent experience with the collapse of fertilizer use when subsidies are removed or prices rise (e.g. in 2008). Developed countries need to reduce production subsidies, regulate nutrient disposal, and implement nutrient trading permits. On the other hand most developing countries should increase input subsidies, implement credit schemes, and extension and training programs to encourage P consumption. Major exporting countries need access to P supplies whereas importing countries need to address problems of P excess in large urban areas, especially where peri-urban animal production creates re-cycling problems (Grote *et al*. 2006).

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Perceptions of grain growers towards their soils in the high rainfall zone of Southern Australia

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Abstract
Dryland cropping in the high rainfall zone (HRZ) of southern Australia has the potential to produce high yields of cereals, canola and pulses. However, actual yields often fall well short of the estimated potential. A survey of grain growers in the HRZ was conducted to gain a greater understanding of the factors which may prevent growers from achieving potential yields. The survey was developed in consultation with growers, soil scientists and agronomists and distributed nationally through an industry magazine. The survey captured grower perceptions of soil and crop management using multiple choice questions and free comment sections. This paper documents the section of the survey pertaining to soils. In this survey, growers throughout the HRZ provided common responses regarding their use of some forms of tillage, trafficking, chemical soil amelioration techniques and physical soil engineering techniques. Different responses were evident depending upon region and farm size for issues such as the use of conventional tillage, raised beds and lime. The perceived success of various types of soil management options is also discussed. This information is valuable for those who wish to identify which regions or grower audiences should be targeted for research and extension in soil management.

Key Words
Survey, farmers, opinions, social, high rainfall zone.

Introduction
The high rainfall zone (HRZ) of southern Australia has the potential to produce high yields of grain crops including wheat, barley, canola and a range of pulses. Consistent yields, particularly in years declared drought in the traditional winter cropping areas, means the HRZ has the potential to significantly contribute to Australia's winter crop production (ABS 2004a; ABS 2004b). So far, productivity increases in the HRZ related to soil management have been attained through reduced tillage, lime and/or gypsum applications, introduction of raised beds to alleviate water logging and recently, adoption of controlled traffic to reduce compaction. These practice changes were principally driven by soil scientists, district agronomists and a select group of highly motivated grain growers. The perceptions of a broad cross-section of grain growers in the HRZ has not previously been canvassed and made available to agricultural soil scientists. A national survey of HRZ grain growers' perceptions of the issues limiting winter crop production was conducted to provide soil scientists and plant breeders with grass roots information to decide the future direction of plant breeding, crop and soil research and practice change programs. The importance of gaining the views of grain growers is obvious if the survey is viewed as a market research exercise where the results can be used to develop products or services that meet grain growers' common needs. An earlier paper focused on the cropping section of this project (Clough et al., 2008).This paper reports results from the soil management section of the survey.

Methods
The methodology used to prepared, distribute and analyse the soil section of this survey is the same as that used for the cropping section of the work which has been published in full in the earlier paper (Clough et al., 2008). However, we briefly outline the methodology for those who are unfamiliar with the earlier publication. The survey was developed using a consultative process with input from growers, agronomists and soil scientists. Pilot questionnaires were assessed by growers who were members of grower groups. The anticipated statistical analysis methodology was tested on the pilot data. Questionnaire and analyses were modified accordingly. The questionnaires were distributed throughout the HRZ to 13,831 subscribers of Ground Cover, an industry publication by Grains Research and Development Corporation (GRDC). Numerical data was analysed using SPSS Version 14.0. Growers' comments were grouped to identify key issues.

Results

Response distribution

An analysis of the survey respondents has been presented elsewhere (Clough et al, 2008). Briefly, the response rate was 3.5% with distribution across the whole target area (Figure 1). Region was the background factor which most often influenced the response of respondents. Analysis of responses is based on geographic regions of New South Wales (NSW), Western Australia (WA) and South-eastern Australia (Tasmania, Victoria and South Australia).

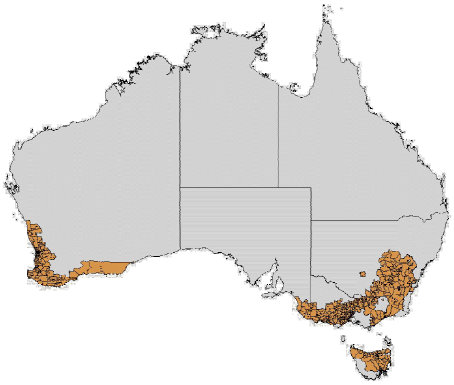

Figure 1. The spatial distribution of returned questionnaires in the high rainfall zone of southern Australia.

Tillage and soil trafficking

The categories provided in the questionnaire covered most options with the proportion of responses in the 'other' category being only 1.3% for tillage practices (respondents = 412) and 4.2% for traffic management (respondents = 398). Respondents were able to acknowledge more than one practice on a farm (i.e. practices are not mutually exclusive), so total responses relative to the number of respondents may sum to more than 100 per cent.

Zero and minimum tillage were uniformly nominated as a practice across all regions with 43% and 69% of respondents choosing those options, respectively. Conventional tillage was more likely to be a nominated practice in south-eastern Australia (32% of respondents in that region) than in NSW (19%) or WA (12%) (P < 0.001 by Z test). Farm size was also related to tillage practice with the tendency for zero tillage practice to increase in frequency whilst conventional tillage decreased as farm size increased (P = 0.007 by Z test) (Figure 2).

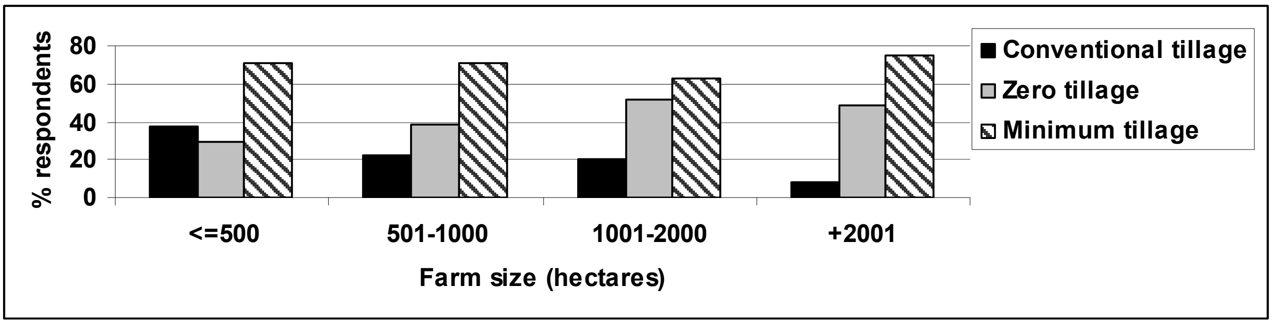

Figure 2. The percentage of respondents to a survey conducted in southern Australia nominating three of the tillage methods relative to four farm size categories. Respondents could nominate more than one tillage method thus the percentages add to more than 100%.

Five trafficking techniques were provided as options. Uncontrolled trafficking was the most common technique nominated (66% of respondents) and there was no difference between regions. Regional differences were found for raised beds which were nominated more frequently in southeast Australia (23% of respondents in that region) than in NSW (1%) or WA (0) (P < 0.001). Nomination of controlled traffic also varied between regions with 17% of respondents in south-eastern Australia nominating the technique compared to only 11% in NSW and 6% in WA. (P = 0.018).

Soil improvement and soil management

The physical and chemical soil management techniques presented to respondents covered most options with only 10% and 17% of respondents nominating ‘other ’ for techniques they had tried (respondents = 405) or would consider trying (respondents = 266), respectively. The proportion of respondents who stated that they had applied gypsum or lime, or had installed raised beds differed between regions ($P < 0.018$) (Figure 3). Regional differences also presented for interest in trying the options of liming, or installing mole or surface drainage ($P < 0.026$) (Figure 4).

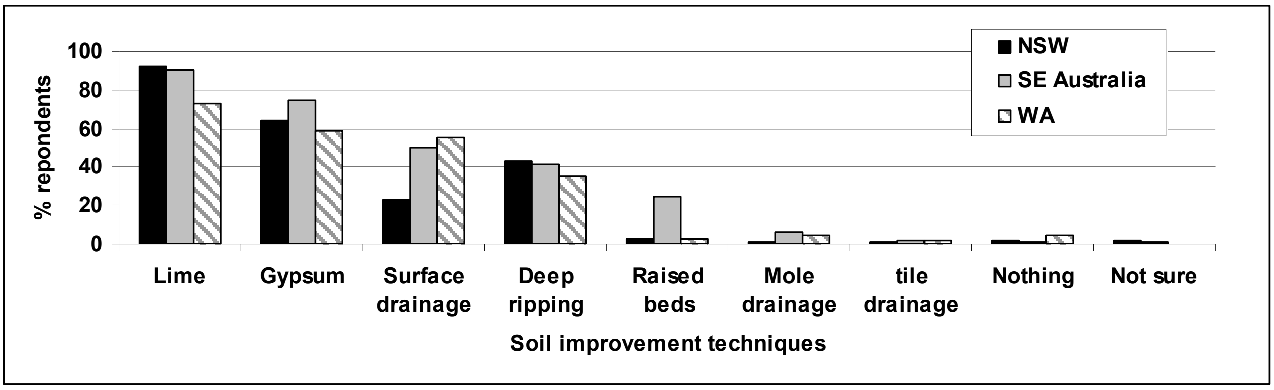

Figure 3. The percentage of respondents in each region of southern Australia nominating the soil management options they have tried as presented in the survey. Respondents could nominate more than one tillage method thus the percentages add to more than 100%.

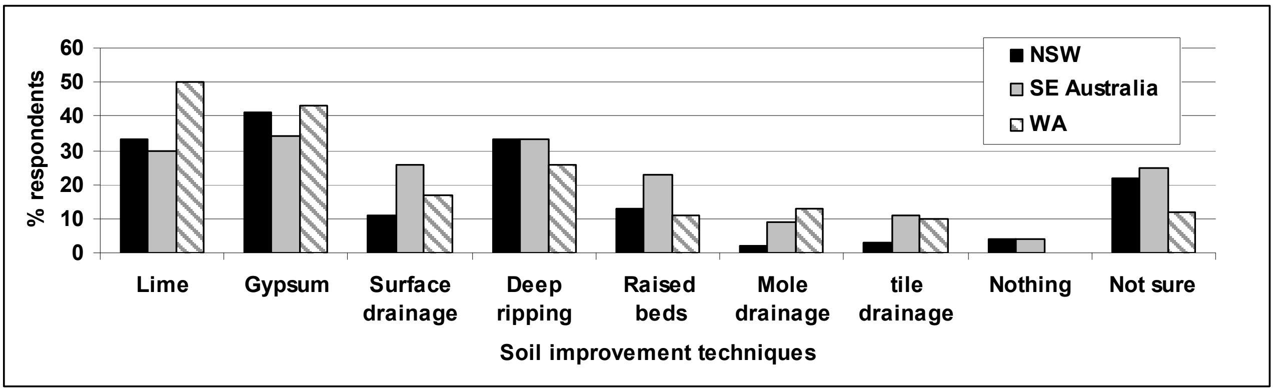

Figure 4. The percentage of respondents in each region of southern Australia nominating the soil management options they would try as presented in the survey. Respondents could nominate more than one tillage method thus the percentages add to more than 100%.

Successful soil management

Table 1. The most frequent responses to the question “What is the best thing you have ever done to your soils to get higher yielding crops?”.

Comment category	Number of comments
Lime and gypsum applied	169
Other fertilisers applied (other than animal manures)	91
Using and expanding crop rotations	90
Reducing tillage	88
Implementing soil engineering including raised beds and drainage	26
Deep cultivation	26
Improving knowledge or accessing information	15
Retaining stubble	15
Total number of comments	603

Respondents utilised the option of stating what they thought was the best action they had ever taken to improve their soils with 603 comments received. Most comments were unique as there was no set format and comments have been grouped for ease of interpretation (Table 1).

Conclusion

The response rate to the survey was low. Potential reasons and implications for this have previously been discussed (Clough et al, 2008). The summary of data and interpretations were presented back to growers at regional meetings and to soil scientists through a fact sheet (DPI, 2006). Both groups agreed that the data and interpretations were logical and within expectations. The information from this survey assists agricultural scientists to discriminate between soil management and soil type as factors limiting crop productivity.

Several target groups for extension and research have been identified as a result of this survey. Reduced tillage has been widely adopted however smaller farms have maintained conventional tillage to a greater extent than larger farms. The survey does not reveal why this is the case and further research may be required to find out whether there is a social or technical impediment to further reductions in conventional tillage on smaller farms. The dominance of uncontrolled trafficking was a notable result of the survey. This was discussed at the SIP08 meeting, Perth, April 2006 where soil scientists pointed out that it is perfectly suitable to drive on dried soil without risking compaction. This reaction serves to indicate a weakness in the original question in which we were trying to ascertain the use of controlled traffic for cropping operations.

The survey highlighted that there has been low adoption of raised beds and low interest in trying raised beds particularly in Western Australia despite the common occurrence of soils prone to water logging. However, about 50% of WA respondents had tried surface soil drainage which may have been a suitable alternative option. The relatively high uptake of raised beds in south-eastern Australia compared to other regions may be related to the raised beds being heavily promoted over the last 12 years in Victoria by farmer groups and the State Department of Primary Industries. A limitation of this survey is that it cannot be used to identify whether respondents elect not to try a soil improvement option, such as liming, because their soil problems have been resolved by previous actions, or no benefit has been seen from previous actions or if there are other financial, social or technical constraints. A clear conclusion of this survey is that respondents are looking to improve their soils but about 20% are not sure how to achieve this objective.

Free commentary can provide insights into respondents views that cannot be encompassed in a structured questionnaire. Although there is a tendency for respondents to favour quick chemical solutions, comments indicate that respondents have a good understanding of how they can improve soils through changing the management of their soils, even in ways that may not have an instant and obvious positive impact.

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Progress towards sustainability – a consensual delusion or viable process?

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Abstract

Projected demands on soils associated with climate change, growth in population and global affluence over the next 40 years are unprecedented. Adoption of more sustainable agricultural practices continues to be secondary to considerations of yield, consumer expectations for cheap food and optimism regarding technological innovation. A changed research focus is required to support sustainable agricultural development. Sustainable soil management must reflect the needs of an ecological system in terms of management practices and inputs.

Key Words

Sustainability, alternative agriculture, soil biology.

Introduction

Agricultural development post World War II has been characterised by high yields and improvements to farm profit. Availability and affordability of food and fibre has greatly increased, but so also has a range of negative environmental and social side-effects that highlight the unsustainability of current practices (Gliessman 2007). Factors that have contributed to agricultural unsustainability include increasing farm size, purchased inputs, specialisation, mechanisation, pollution, loss of biodiversity, dependence on subsidies, vertical integration and global markets (Hill 1995). Social and economic pressures have resulted in management practices that negatively impact on soil quality and quantity. In the United States, it is estimated that soil loss is proceeding at a rate of 17 times the rate of soil formation (Warshall 2002). Globally, about one tenth of the world's arable area (1.2 billion ha) is affected by serious degradation with about 300m ha now unusable (UNEP 1997). In Australia, a range of evidence tells a similar story (Schoknecht 2009; SoE 2009; Sims and Cotching 2000). Projected demands on soils associated with climate change, growth in population and global affluence over the next 40 years (UNEP 1997) should register deep concern in the context of our poor record of management of this most fundamentally important natural resource.

Discussion

Whilst there is general optimism that with adoption of modern agricultural practices, use of improved crop and livestock varieties, free trade arrangements and more equitable land ownership the challenge of future food security can be met, there is real concern about the capacity of natural systems to sustain the required level of output (Cribb 2006). Much of the increase in agricultural output over the past 40 years has come from an increase in yields per hectare rather than an expansion of area under cultivation (MEA 2005). In his address to the 2006 National Soils Conference in Adelaide, Australia, Professor Julian Cribb asserted that 'If there is to be a second agricultural revolution then it is my belief that it is from the soil – rather than the biotech lab alone – that the next great leap in farm productivity will arise' and the drivers of this revolution will be '...the conservation, manipulation and management of populations of microscopic plants, insects, fungi and bacteria (which) will determine productivity at the surface'.

Given the concern about the capacity of natural systems to sustain the required level of output, and to do so indefinitely, a commitment to sustainability requires research in soil science to focus on the needs of soil as an ecological system. Treatment of the soil as an ecological system will result in management practices that conserve and enhance ecosystem services provided by the soil in ways that reduce negative trade-offs or that provide positive synergies with other ecosystem services (Lavelle *et al.* 2006). Traditionally, soil science has been reductionist, aiming to unlock the complexities of soil processes by analysing their constituent parts and seeking to solve one problem (Stocking 2007). The growing threats to the sustainability of our soil resources requires a change of thinking to one more suited to the dynamic characteristics of soil ecosystems. "If agriculture does move to embrace an ecologically-sympathetic approach, the great scientific challenge for the coming years will be to understand more fully the life in our soils and how it may be better managed for food production and environmental renewal" (Cribb 2006).

Within the broad farming community there is a growing awareness of the need to adopt more sustainable land management practices (Oakeshott 2008). In the author's experience, many farmers in Tasmania and New South Wales are looking beyond traditional sources of information because of dissatisfaction with declining outputs and realisation that conventional practices are not building health into their soil resources. Change towards sustainability requires a paradigm shift from a focus on maximising yield and a belief that technological innovation can resolve all problems to one where ecological health is valued. In order to map a path towards sustainability, measures of ecological health that are appropriate to agricultural landscapes, and particularly soil resources, are required. This will involve some conception of the condition we expect in our soils, in 10, 50, 100 or 500 years from now.

Proponents of alternative agriculture (biological, organic and agroecosystem farming) are motivated by a belief in the sustainability of an ecological approach. However, opponents of alternative agriculture claim that only conventional, high production agriculture can feed the world (e.g. former US Secretary of Agriculture Earl Butz in Beus and Dunlap 1990) and that alternative agriculture should be dismissed as merely a new theory, a philosophy and not based on science (Wynen 1996). A substantial body of scientific research now shows that alternative agriculture is economically viable and has the capacity to meet much of the world's needs for food and fibre (e.g. UNEP 2008; Pimentel *et al.* 2005; Ashley *et al.* 2003; Ching 2002; Wynen 1996). However, a wholesale shift to organic agriculture, particularly in developed countries is not regarded as immediately practical, partly due to a predominance of negative perceptions among farmers, researchers and agri-business and partly due to the lack of extension capacity to guide changes in management practices. In addition, the decline in numbers of farmers with complex knowledge of natural systems is also a major limitation (Halweil 2000).

The development of agro-ecology as a discipline recognises the potential advantages of working with, and mimicking natural systems for sustainable production outcomes and protection of biodiversity (Gliessman 2007). However, wholesale adoption of agro-ecosystem principles and practices in the developed world is also unrealistic in the short-term as it shares many of the same impediments to adoption as identified above for organics, not least of which are the knowledge and commitment required for successful implementation. Time and research effort is needed to overcome these impediments. Of the alternative systems of production, biological agriculture has the greatest potential to contribute to agricultural sustainability in the short- to medium-term. Biological (or eco-) farming is rapidly growing in Australia, the United States, New Zealand, South Africa and Europe. It is a recognised hybrid system that aims to take the best from conventional and organic systems, promote biological health and maintain yields with judicious use of inputs. Biological farming represents a practical and positive development in view of its: improved ecological focus; improved focus on soil management; broad compatibility with existing production systems; compatibility with technological innovation; focus on system health; and focus on quality outputs (Zimmer 2000; Wheeler and Ward 1998).

A biological approach differs from conventional approaches in subtle but important ways. For example, nutrient management is not wholly based on the 'sufficiency level of available nutrient' concept which aims to supply nutrients to a 'critical level' at which point there is little or no crop response to further additions of that nutrient (Zimmer 2000). Rather, inputs are provided to maximise the growing potential and pest / disease resistance of crops. For example, Fitzgerald *et al.* (2003) showed that the pH and calcium required for optimal plant health in bananas was higher than that required for optimum yield but resulted in a significant reduction in Sigatoka pressure and the need for fungicide applications. Similarly, Zimmer (2000) reported significant reduction in leaf hopper pressure on potatoes with increased application of soluble calcium. Such responses to pest and disease pressures can contribute to improve biological functioning of soils, improved plant health and improved product quality (Zimmer 2000). This approach requires fundamentally different thinking to the control of pests and diseases with pesticides but ironically, it does not require a major change in the tools used. Research is needed to further examine the costs and benefits of this kind of response to pest / disease pressure with regard to the efficacy of treatments, relationship with soil biological function and soil condition, and product quality. Given that biological agriculture is largely compatible with current agricultural practices and supports the use of most conventional inputs, albeit in a way that protects and enhances ecological processes, it stands that a more biologically / ecologically sympathetic RD&E program that is multidisciplinary and holistic can deliver substantial improvements in our understanding of how to manage our natural resources, and particularly our soils, sustainably.

Conclusion

There is a slow shift towards development of a national Soils Policy in Australia and most regional Catchment Management Authority strategic plans have soil condition targets. However, at this time, most plans and policies still lack a clear articulation of the need for, and a path to sustainability. Unfortunately the reduction of government-sponsored extension could not have come at a worse time. The popular idea that the market will meet the needs of business does not hold for considerations of sustainability. Without appropriate extension to support a transition to more ecologically-focused soil management existing paradigms will hold fast. In the face of economic, market, consumer, peer and institutional pressures, farmers can not make this change alone. The change to sustainable management of our soil resources requires the support and commitment of Governments, universities, agricultural (and soil) science communities, agri-business and consumers. The reality is that (under current timeframes) we are effectively dealing with a non-renewable resource. Investment in sustainable soil management is an investment in our collective future.

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Relevance of soil and terrain information in studies of major global issues

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Abstract
Society at large is increasingly aware of the need to make better use of the world's natural resources to secure and improve the livelihood of billions of people. The increasing amount of food and non-food commodities required from agro-productions systems will have to be produced on an ever-declining base of natural resources per person. Consequently, the use efficiency of natural resources will have to be enhanced drastically. The role of soils should be better understood and exploited to this aim. ISRIC - World Soil Information collects, stores, processes and disseminates global soil and terrain information for research and development of sustainable land use. It pleads to position soils more prominently in global debates by highlighting their functions in processes of global change and major development issues.

Key Words
Soil, water, nutrients, biodiversity, food production, climate change.

Introduction
The functioning of global agro-ecosystems is dependent on the epidermis of the Earth – the soil. This natural resource has often been undervalued but awareness of its importance is improving. In economic analyses, production in regions with high land prices is allocated to regions with lower prices, with virtually no attention paid to the inherent characteristics of different soil types. Analyses of global development issues, including climate change, food production and biodiversity, give limited consideration to soil and land information. However, plants, as primary supporters of life on earth, root in soils, which supply them with water and nutrients. Moreover, since soils contain many of the elements in global cycles, including carbon, oxygen, nitrogen and water, they play a major role in balancing global processes. The greatest biodiversity is also found in the soil.

Soil formation is a very slow process that requires roughly one century to form one centimeter of soil, whereas processes of degradation may occur at a much faster rate, leading to net loss of soils. Often, the top 20 cm of soils determine their productivity, highlighting the potentially large impact of degradation on soil productivity. Scenarios for maintaining or improving the functions of soils therefore should become an integral component in global analyses.

Land requirement
Agricultural land per person will continue to decrease due to population growth and loss of fertile lands to urbanization and physical and chemical degradation. The availability of suitable agricultural land is severely limiting in most Asian countries with little space for expansion. Asian countries will have to rely increasingly on food imports (WRR 1995). Latin America inherits large potential to export food, certainly with expansion of the agricultural frontier. Expansion of agricultural land however, comes at the expense of biodiversity and creates large emissions of greenhouse gasses (GHG). In sub-Saharan African countries, land is abundantly available relative to the low population densities, though overall soil quality is poor, heavily depressing yield levels.

The total arable area will need to increase by about 200-300 million ha in the coming two decades just to meet food demand (see Bindraban *et al*. 2009). Other requirements for land, such as from agro-energy, are not yet considered in these estimates, as are changes in soil quality. According to Bai *et al*. (2008), the decline in the quality of soil and vegetation, based on remotely sensed imagery, indicates that 24% of the global land has been degrading over the past 26 years - often in very productive areas. However, there is hardly any overlap with the qualitative GLASOD study that recorded the cumulative effects of land degradation up to about 1990 and indicated that 15% cent of the land area was degraded at the time (Oldeman *et al*. 1991). The numerous factors driving the change, such as rainfall, temperature, CO_2 concentration and indeed soil characteristics, and their strong interactions, should, however, be explicitly considered following production ecological approaches (Van Ittersum and Rabbinge 1997) to relate these changes to soil quality.

Location specific fertility
A shortage of several key nutrients in soils can limit yields. In Africa, for instance, food production systems are constrained by overwhelmingly low soil fertility. Following the concept of De Wit (1992) that 'most production resources are used more efficiently under improving conditions of resource endowment', synergies and interactions between production factors at various scales should be explicitly considered in analysis of production systems to arrive at agro-technical strategies for enhancing productivity.

Bindraban *et al* (2008) showed that yields in Europe were 3 t/ha in 1961 at high fertilizer rates and increased to 8 t/ha in 2000, at similar fertilizer rates because of improved overall management practices and advanced technologies such as improved varieties. Breman *et al*. (2001) illustrated that only the synergistic effect of the combined use of organic and inorganic fertilization was able to increase yield over time in the semi-arid Sahelian region due to increased nutrient supply. Similarly, many others reported synergistic effects between soil nutrients and soil water-nutrient interactions. These insights underline the need for soil information to be location specific and to report the availability of both macro and micro nutrients. This type of detailed soil information, will have to be collated by soil survey organizations with a national mandate, for possible incorporation into ISRIC's continental and global scale databases.

Green water
The linear relation between plant biomass and transpiration, implies that greater biomass production requires more water for transpiration. The total amount of fresh water needed for the production of food in the world in 2005 has been estimated at 4,831 to some 7,000 km^3. Some 1,800 to 2,660 km^3/yr is provided by irrigation water. Feeding 9 billion people in 2050 is estimated to require 6,800 to 8,500 km^3 (Bindraban *et al*. 2010). Assuming unchanged irrigation, a total of 5,000 to 6,500 km^3 from the 11,970 km^3/yr falling on arable land should be converted into transpiration.

Molden *et al*. (2009) are cautiously optimistic about possibilities to improve water use efficiency as they warn that these will not be attained easily. Observed yields in a semi-arid Mediterranean-type environment are 100–400% below the maximum yield that can be obtained given the availability and best use of the rainfall (French and Schultz 1984). Other factors such as N, phosphorus (P), micro nutrients and diseases were greater limiters of yield than water availability. These findings are true in general for semi-arid regions. In order to increase and stabilize yields, seen the erratic nature of rainfall, soil water storage and retention properties should be improved using best management practices.

Soil biodiversity
Soils contain one of the most diverse assemblages of living organisms. Several soil organisms are known to be essential for the various chemical and physical processes, including decomposition of organic matter, immobilization of nutrients, and formation of pores. Whereas the diverse forms of life have their intrinsic value, it is important to understand the functionality of the organisms for the provision of goods and services.

Nitrogen fixation of bacteria in symbiosis with plants is a good example of such functionality. Quantitative plant growth can, however, be modeled on the basis of soil chemical and physical processes, that sufficiently accurately mimic the role of soil organism on soil processes. Some claimed that enhanced soil biodiversity would increase the use efficiency of (organic and inorganic) fertilizers. Langmeier *et al*. (2002) found however no such effect on two soils that were highly distinctive in terms of organic matter and biological activity, after 20 years treatment with organic manure and artificial fertilizers, separately. While positive impacts are also reported for specific conditions, Brussaard *et al*. (2007) state that the linkage between biological activity and C and N mineralization and stabilization as soil structure dynamics is not straightforward and that quantitative assessment of soil macro fauna on abiotic processes like water and nutrient fluxes appears hard. While it could be reasoned that the functioning of ecosystems may be impaired by the loss of soil biodiversity, evidence is ambiguous. As it is yet unclear what indicator should be used for soil biodiversity, information on this soil characteristics cannot (yet) be systematically collected.

From soil science to ground truth
Soil science has evolved from descriptive observations of field conditions to quantitative insights about physical, chemical and biological processes of soils. The collated information, however, often is not directly applicable by private enterprises, NGO's, researchers, nor suited to support policy decisions (Bouma and Droogers 2007).

Conventional soil surveys, including field description, sampling as well as selected soil chemical and physical analyses, lead primarily to reports presenting classification, soil maps and qualitative land evaluation. Other disciplines, including crop scientists and hydrologists, need more functional characteristics of soils to assess soil and land quality. However, for many regions, the necessary primary data simply are not available at the required resolution, in particular for soil physical analyses. Further, the available data have been analyzed according to a range of analytical procedures which need not be comparable.

To fill gaps in the measured data, providers of soil information need to apply transfer functions and expert judgment (e.g. Batjes *et al*. 2007; Van Ranst *et al*. 1995; Wösten *et al*. 2001); more sophisticated techniques are now being tested (Malone *et al*. 2009). Uncertainties associated with differences in measurement of, for example, particle size distribution and bulk density will be reflected in the accuracy of pedotransfer and other functions derived from the primary data. Cross-correlations between uncertain variables determine how uncertainties will propagate in a modeling study (Heuvelink and Brown 2006). Accuracy levels considered to be acceptable will vary with the scale and type of questions being asked (Finke 2006). Many of the ISRIC databases, such as e-SOTER and WISE, are specifically developed for applications at continental and global scales (1:500 000 or broader). More recently, finer resolution soil property maps are being developed in the framework of the GlobalSoilMap.net Project (Sanchez *et al*. 2009).

Knowledge and information needed to govern many current developments in the world call for integrated global analyses. Consistent global soil information systems are essential to assess issues such as global food production potential (WRR 1995), global agro-ecological zoning, estimation of global terrestrial carbon sequestration**,** or climate change processes. Expansion of agricultural land for the production of food and bio-fuel causing loss of biodiversity and emissions of Green House Gasses (GHG), displacement of poor people by large scale undertakings and the like call for global analyses (Bindraban *et al*. 2009). Soils play a major role in many of these processes but have so far been under-considered. More ground work has to be done by the soil science community to link up with these global developments.

ISRIC and World Soil Information

The concise description on land, water, nutrients and biodiversity indicate that much knowledge is available about specific processes, but application for global analyses call for more detailed, global soil database that would enable climatologists, hydrologists, crop modelers, foresters and agricultural scientists, among others, to better predict the effects of global change, with defined uncertainty ranges. ISRIC - World Soil Information will act as a coordinating institute in collecting, storing, processing and disseminating global soil and terrain information for research and development of sustainable land use; our current international projects (www.isric.org/UK/About+ISRIC/Projects/) will serve as vehicles to this aim. The Global Earth Observation System of Systems (GEOSS) will serve as a platform to communicate developments in world soil information to policy circles and the general audience.

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Site suitability assessment for sustainable forest plantation establishment of *Dyera costulata* in a West Malaysian tropical forest

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Abstract

The recent depleting resources in global wood supply have prompted the need to establish forest plantation to compensate for the reducing commodity. *Dyera costulata* has been earmarked as one of the potential species for forest plantation establishment. The objective of the study was to evaluate the topsoil chemical and physical properties of a lowland tropical forest for *Dyera costulata* plantation establishment. Standard soil survey method was used for surveying before composite soil samples were taken according to each soil series, namely Batang Merbau (BMU), Bungor (BGR) and Semantan (SMN) at 0-30 cm depth. Soil samples were subjected to standard soil chemical and physical analysis. All soils were well drained except for SMN. Sand content varied from the range of 48-74%; silt (4.5 – 11%) and clay (18-50%). Nitrogen (N), phosphorus (P), and potassium (K) contents were low in all soil series. The carbon concentration in SMN was the highest, 1.6% which was 44% and 25% higher than BMU and BGR respectively. The soils showed a pH range from 3.9 to 5.0. Magnesium (Mg) and calcium (Ca) were abnormally high in SMN but was low in BGR and BMU. The CEC increased in the order of BM<BG<SM.

Key Words

Soil properties, planted forest, tropical soil, physical characteristics, nutrient requirement.

Introduction

The surge in economic development and industrialization activities in the current global trends has concurrently increased the demand for wood supply. The continuous exploitation of natural forest for timber has called for desperate measures in establishing sustainable forest harvesting and forest plantation. Plantation forestry can supply timber, reduce deforestation, restore degraded soils, enhance biodiversity, stabilize carbon sinks and provide revenue for local economy. In Malaysia, there are plans by the government to increase the forest plantation area from 250,000 to 500,000 ha (FRIM, 2007). One such indigenous species selected for reforestation is *Dyera costulata*. This threatened fast-growing indigenous timber species from the family *Apocynaceae* can be found in Peninsular Malaysia in lowland secondary forests. *Dyera costulata* is mainly used for artistic tools such as pencils, picture frames, carvings and furniture making. Successful *D. costulata* forest plantation ventures would rely on suitable climate, topography, species, and other inherent soil properties. Soil physical, chemical, and biological characters are important determinants used in the selection of sites for plantation forest. Thus, the objective was to evaluate the soil physical and chemical properties of a lowland tropical forest for successful *D. costulata* plantation establishment.

Materials and methods

The site, covering 811 ha was located at Semantan, sub-district of Temerloh in Pahang, West Malaysia (3^o 25' N;102^o 12' E). The area was covered by secondary forest, mainly *Acacia mangium*, shrubs and bushes. The mean annual rainfall from 2004 -2007 was 1800-2030 mm and the temperatures ranged from 23^{o}C to 34 ^{o}C respectively for the same period. A standard semi-detailed soil survey was undertaken (Soil Survey Division Staff 1993). Traverses were established every 800 m intervals in an east-west direction to cut across major geological formations which was present from north to south. Soil inspection was done at regular depth of 20 cm to 120 cm depth using a Jarret auger at fixed distances of every 200 m along the traverse. However, only topsoil information (0-30 cm) was presented due to space constraints. Soil sampling was carried out for determination of physical and chemical properties using standard soil chemistry laboratory analysis methods. The terrain classes were delineated using a topographical map and verified in the field using a clinometer. Three soil pits were dug to be examined and described and they represent the most dominant profiles, namely Batang Merbau (BMU), Bungor (BGR) and Semantan (SMN) series.

Results

The complete analytical data was used for the classification of soil series were not presented here due to space limitations. Generally, all profiles were deep soils and had subangluar blocky soil structure at different variations (Table 1). SMN was developed on riverine alluvium whereas BGR and BMU from argillaceous parent materials. BMU and SMN soils had sandy clay texture, but BGR had a clay texture. BMU and BGR were well drained however, SMN was not. Only BMU was found on undulating to very hilly topography compared to SMN on undulating terrain, and BGR on undulating to rolling terrain. All three soils exhibited high contents of sand in the topsoil, which was from the range of 44-71% (Table 2). The silt content was fairly low, between 5 – 11%. The highest clay content was in SMN (49.5%), followed by BGR (26%) and 18% in BMU.

Table 1: Soil description of major soil series in Semantan sub-district, Temerloh Pahang.

West Malaysian classification	USDA classification	Slope	Degrees (°)	Area (ha)	Description
Batang Merbau (BMU)	Typic Paleudults	Undulating to very hilly	2-6° to 12-20°	461	Deep soil (>100cm), brownish yellow (10YR 6/6), fine to medium sandy clay, moderate medium & coarse subangular blocky structure medium & coarse subangular blocky structure, friable to slightly firm, well drained
Semantan (tentative) (SMN)	Aquic Hapudults	Undulating	2-6°	90	Deep soil (>100 cm), gray (5Y 5/1), fine sandy clay to fine sandy clay loam,moderate medium and coarse subangular blocky structure, presence of manganese and quartz grain, slightly firm to firm,imperfectly drained
Bungor (BGR)	Typic Paleudults	Undulating to rolling	2-6° to 6-12°	260	Deep soil (>100 cm), strong brown (7.5YR 5/6), fine to medium sandy clay to heavy clay, moderate medium and coarse subangular blocky structure,slightly firm to firm,well drained

Nitrogen contents were lower than 1% for all soil types. The carbon concentration in SMN was the highest, 1.6% which was 44% and 25% higher than BMU and BGR respectively. Base saturation level in SMN was higher than BMU and BGR, 2-fold & 7-fold respectively. The availability of P was considered very low which was less than 4 mg/kg for all soil types. The soils showed pH range from 3.9 to 5.0. Potassium was also in the low range, which was less than 0.5 cmol/kg. Mg was abnormally high in SMN but was poor (low) (less than 0.1 cmol/kg) in BGR and BMU. The CEC increased in the order of BM<BG<SM.

Table 2. Chemical & physical properties major soil series at 0-30 cm depth in Semantan sub-district, Temerloh, Pahang.

West Malaysian classification	Sand	Silt	Clay	N	Org. C	Base Saturation Percentage	Available P	Dry pH H_20	K^+	Mg^{++}	Ca^{++}	CEC
	%						mg/kg		cmol/kg			
Batang Merbau (BMU)	71	11	18	0.1	0.9	5.4	3.6	4.2	0.04	0.03	0.07	5.0
Semantan (SMN)	44	6.5	49	0.2	1.6	10.9	3.4	5.0	0.04	0.53	1.32	17.6
Bungor (BGR)	69	5	26	0.	1.2	1.6	2.9	3.9	0.05	0.09	0.0	14.0

Discussion and recommendation

Only deep (> 100 cm) soils with suitable drainage of the BMU and BGR soil series were considered as *Dyera costulata* requires deep and well drained soils (Ab.Rasip *et al.* 2004) [Table 1]. However, establishment of forest crop was not advisable on terrain of more than 25^o for BMU due to erosion risks and problems due to establishment and management. SMN was only marginally suitable due to poor drainage, which may cause ponding effects during heavy rainfall. Construction of drains or trenches may help to drain excessive water if planting was considered. Soil texture had major effects on forest species growth, especially on water holding capacity, aeration and organic matter retention (Fisher and Binkley 2000).The soils of the surveyed area were moderately fine textured (Table 1), where clay content was more than 20% (Table 2), which was suitable for proper root growth and anchorage.

Although a clear standard on soil chemical requirements for tropical forest species in Malaysia is unavailable, it is common that *Hevea brasiliensis* (rubber) is used as a benchmark for tree plantation. Our results for N, P and K showed very low concentrations compared to guidelines suggested by Pushparajah (2009) which was 0.11-0.2% for total N, 251-350 mg/kg for available P and 0.51-2.0 cmol/kg for exchangeable K, respectively. In tropical soils, the P content is relatively low due to many reasons such as insoluble complexes, precipitation by ferum, aluminum and manganese ions and also they are easily susceptible to fixations (Friesen and Blair 1981). Low levels of N, P and K can be compensated with applying standard NPK 12:12:12 fertilizer (50 -100 g) into planting hole (Krishnapillay 2002) with organic amendments as a starter boost for this species. Periodic fertilization will become necessary to maintain a uniform growth of *D.costulata* for favourable production.

In forest plantations, hardy species such as *D. costulata* has the ability to withstand low to slightly acidic pH, between pH 4-5. This is quite common in forest soils predominantly due to exchangeable aluminum. Soil ameliorations with ground magnesium limestone (GML) which has Ca and Mg source is recommended for both BGR and BMU if pH drops below 3.5, to maintain important nutrients such as N, P, K, Ca, Mg and micronutrients. The low to moderate levels of CEC and base saturation were normal in tropical forest soils due to the acidic nature of the soil caused by excessive leaching associated high tropical rainfall (Lim 2003). High base saturation in SMN was correlated with the high levels of Mg and Ca in this soil, although these bases are believed to be transported by river from external limestone sources.

Conclusion

There were no serious limitations to the use of the surveyed area for *Dyera costulata* plantation except for areas with extreme slopes in Batang Merbau. The low inherent fertility status of Bungor and Batang Merbau Series can be overcome by adequate fertiliser application. Semantan was marginally suitable and adequate drainage management is required.

Acknowledgements

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Soil carbon depth functions under different land uses in Tasmania

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Abstract
Agricultural soils play an important role in the global carbon cycle and can act as a significant carbon sink if managed appropriately. Thirty soil cores were sampled from five different land uses across a consistently mapped Brown Dermosol in the Midlands region of Tasmania. Each core was separated at three depths (0 – 10, 10 – 20, 20 – 30 cm) to generate 90 samples. Each of these samples was analysed for total organic carbon (TOC) to assess the effect of the different land uses on soil carbon dynamics with depth. As expected, TOC levels in the topsoil were depleted under intensive land management practices, however the carbon levels in the subsoils suggested that increases in land use intensity resulted in higher TOC levels below 10 cm. This emphasises the importance of sampling at depth when assessing soil carbon dynamics in relation to land use. After 12 years of intensive cultivation however, some fields showed little change in TOC levels, which is likely a function of the protective nature of the high clay and silt content (~70%) of the soil and the associated use of minimum tillage. If Australia enters into a CPRS and agriculture is included, recognition of the role of subsoils as a carbon sink will be necessary in ensuring carbon taxes are appropriately administered.

Key Words
SOC dynamics, land use intensity, sampling depth, CPRS.

Introduction
As a result of Australia's ratification of the Kyoto protocol, and the intent by Australia to introduce a carbon pollution reduction scheme (CPRS), a need exists to properly define realistic carbon sequestration options with sound scientific evidence that could eventually underpin policy changes in the future. Having defensible knowledge as to the potential of Australian soils to sequester carbon will be crucial in ensuring that soils are included as a potential sink for atmospheric CO_2 in any future developing carbon pollution reduction scheme. For soils to be included in a potential CPRS, scientific evidence must consistently demonstrate the effect of different land uses on soil carbon levels, and these changes must be shown to be easily quantifiable. The majority of previous studies quantifying the effect of land use on soil carbon have mostly just measured changes in the topsoil (~15cm). The aim of this research was to assess changes in soil carbon at depth in response to increasing levels of land use intensity.

Materials and Methods
The data used in this research was collected from the property "Lowes Park" in the Midlands of Tasmania. The property has five centre pivot irrigators that overlap with an area of consistently mapped soil type (Leamy 1961). From these five overlapping fields, four were selected and used as sample sites. At each sample site, five soil cores were extracted with a truck mounted hydraulic push-tube apparatus, and from each core five sub-samples were taken at the following depths: 0 - 10, 10 - 20, 20 – 30 cm.

Five randomly sampled soil cores from six separate sampling sites provided in the extraction of 30 total soil cores. From these soil cores, 150 individual samples were generated, air-dried for a week and weighed for calculation of bulk density.

The 90 samples were sieved at 2 mm to remove any stones, or large organic material. Post sieving, each individual sample was sub-sampled and a portion of that sub-sample was milled for 20 seconds in a Retch MM200 ball mill to allow for complete disaggregation of all solid clay particles and soil aggregates. This allowed for complete combustion of material during the analysis process. Analysis total organic carbon (TOC) was performed on 20 - 30 mg of milled soil, on a Perkin-Elmer CNH dry combustion analyser.

For analysis of mineral associated carbon, a 20 g oven dry sample of each soil was dispersed in 100 ml of water containing 2.5 g of the dissolved chemical dispersant calgon (sodiumhexametaphosphate). The samples were put into 250 ml centrifuge tubes, and placed on their side on a horizontal shaker at 175 rpm for 16 hours. The suspended soil was then washed over a 53 µm sieve, taking care to account for the entire

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initial sample. The material was washed gently on the sieve with distilled water until the water running through the sieve appeared clear. Both fractions were recovered and the samples dried at 60°C until the water used in the separation process had evaporated. Each fraction was weighed, and the dried <53 µm fraction was milled, and analysed again for the carbon content. The calculation for the carbon content of the >53 µm fraction was calculated by difference from the TOC data set after accounting for the bulk density.

Relative land use intensity was calculated by assigning numerical values to particular land management practices, the sum of which was calculated for the period of cultivation and divided by the calculated intensity of the control site.

Results

From the 90 data points collected, the mean TOC values for each field can be compared. The experimental design aimed to have two key land uses. However when specific land use histories were collected a distinct difference between Field 1 and the remaining fields became apparent. Figure 1 below reveals the general trend in TOC content with depth, information about the variation in the results obtained, and specific differences and trends between individually sampled fields.

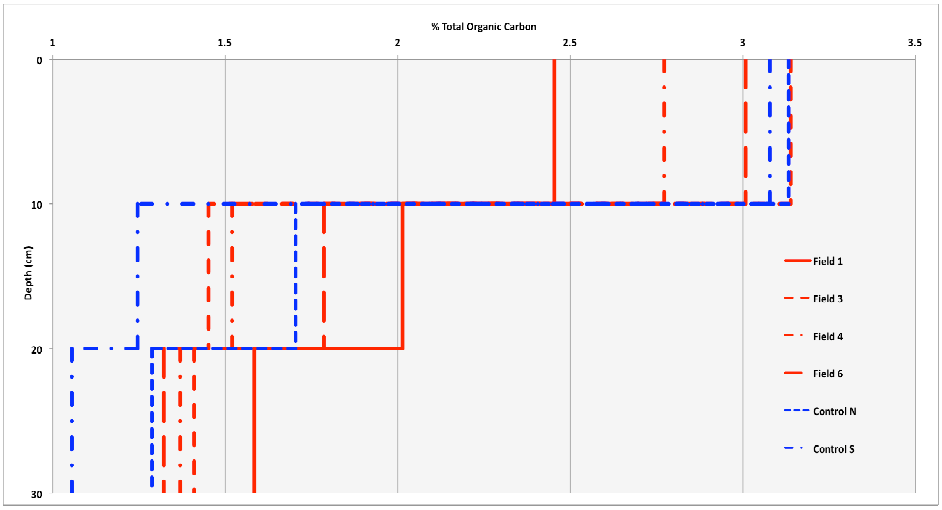

Figure 1: Graph showing TOC dynamics at depth for each sampled field. Each value is the mean TOC content of the 5 cores taken at that site. In the 0 – 10 cm section both control sites, Field 6 and Field 3 have relatively high carbon levels. The values of the 10 – 20 cm section are particularly variable, however Control South has low levels of carbon compared to all other sampled fields. Both values for the control sites are lower than all the sampled field sites for the 20 – 30 cm section suggesting the cropping is increasing carbon levels deeper in the soil profiles. Field 1 has significantly less carbon in the topsoil, relative to all other sampled sites, but has relatively high TOC levels in the soil deeper than 10 cm.

The calculation of relative land use intensity allows for the comparison of TOC content at depth for different fields whilst accounting for the different land use histories.

Figure 2: Table of relative land use intensity. Green represents established pasture or lucerne (1). Yellow

represents the cultivation of annual cereals using direct drilling (2). Orange represents the cultivation of annual cereals or poppies with conventional tillage (disc and harrow) (4). Red represents a deep tillage event following the production of potatoes (8). The sum of these assigned values gives a score, which is divided by the value for the control to give a value for relative land use intensity.

Relative land use intensity can then be plotted against the TOC values at all depths for the associated fields.

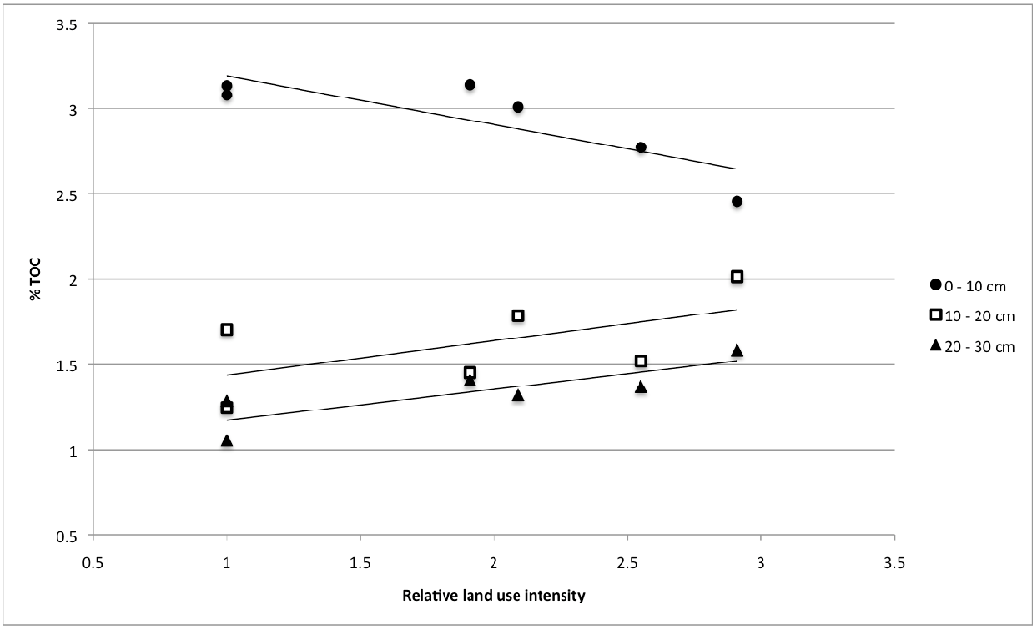

Figure 3: Graph showing relationship between TOC percentage and relative land use intensity for the three sampled depths. Note the inverse relationship in the 10 – 30 cm soil section under increasing land use intensity. This suggests either carbon burial, increased root growth and subsequent carbon deposition, or the accumulation of soluble organic carbon in the more intesive land management practices. Topsoils show the expected decline in soil carbon with increased intensity of use.

Discussion

Sampling sites of particular interest from Figure 1 are Control South and Field 1. Control South showed the greatest difference between the TOC value for the 0 – 10 cm soil section, and the TOC value of the 10 – 30 cm soil section. Conversely, Field 1 had an almost linear decline in TOC content with depth, a feature possibly attributable to a deep tillage event in 1998 (Figure 2). In the topsoil, Field 1 had 20% less TOC than Control South, a figure consistent with other land use studies into agricultural practices of high intensity performed in Tasmania (Sparrow 1999). The values for Control South and Field 1 are statistically different at every depth.

The two control sites had very similar amounts of carbon in the 0 – 10 cm soil section, however in the 10 – 20 cm section, Control North was not statistically different to any other field site except Control South. The difference between the controls decreased in the 20 – 30 cm soil section, however the value for Control North was more similar to the intermittent cropping sites. Sampling control sites was necessary to assess variability of carbon levels across the landscape. It should be noted that at the time of sampling, these pastoral soils had been subjected to an extended drought, which may have been responsible for a degree of soil degradation. This result is suggestive of the difficult nature of soil carbon measurement, and the difficulty in assessing whether differences in carbon measurements are a function of natural variation or of different land management practices.

In general, the establishment of perennial systems such as lucerne or improved pasture results in increases in soil carbon content (Contant 2001). Since lucerne is a deep-rooted perennial, the high level of carbon in the 10 – 30 cm section could be a function of the long term deposition of carbon to those depths, or mixing by deep tillage.

These interactions discussed above are summarised in Figure 3. Figure 3 shows the trend of TOC content for increasing land use intensity for each depth, regardless of field. As expected and suggested in the relevant literature, the carbon content of the topsoil decreases with increasing land use intensity (Lal 1997). However what is of most importance in this graph is the dynamics of the carbon associated with the soil deeper than 10 cm. This graph shows that an increase in land use intensity, and thus presumably productivity, results in an increase in carbon associated with that soil. This indicates the crucial importance of sampling at depth when assessing carbon stocks or the dynamics of soil carbon associated with changes in land use.

The lack of significant change in TOC content for various land management practices suggests the resilience of these soils to carbon loss. Despite heavy usage over a 10 – 12 year period, TOC levels in soils have changed very little. This is complementary to other studies assessing the effects of agricultural management on Dermosols in Tasmania, which suggest that despite their intense use, these soils are still in good health (Cotching 2002). The resilience of these soils to carbon loss is likely a function of the high clay and silt content of the sampled soils (~70% clay and silt content). Published evidence indicates that one of the principle factors in physical protection of organic matter in soils is its ability to associate with clay and silt particles (Hassink 1997). Therefore, soils with a higher clay and silt content will show a greater resistance to the degradation of organic matter.

Conclusion

The major finding of this research was that the process of intermittent cropping, and the associated increases in the productivity of the soil, resulted in the accumulation of carbon at depths below 10 cm. Although in this research the TOC deficit incurred in the topsoil was not exceeded by the gains made in the mean subsoil levels, this work is suggestive of the potential of subsoils as a strong carbon sink. More research into carbon dynamics at depths below 10 cm could confirm the use of subsoils as a significant carbon sink. If a CPRS is established and agriculture included, this will be a vital avenue of soils research. The challenge for soils scientists is to reliably predict the quantity of carbon that could be sequestered by the implementation of certain agricultural practices. For soils to be included in a CPRS, the action of sequestration and the dynamics of carbon in soils must be defensible and backed up with significant data of relative consistency. This appears to be the major challenge facing the potential of soils to become part of a CPRS.

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Soil fertility as a limiting economic factor for sustainable biodiesel feedstock production

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Abstract
Sustainable production of biofuel feedstock encompasses social, environmental and economic issues that often overlap. In Florida, concerns over replacing food production with fuel production and the accelerated loss conservation and riparian easements can be mitigated through the integration of feedstocks into existing horticultural production systems. In this capacity, the feedstock functions as a beneficial rotational crop that mitigates the build-up of soil-borne pest population, a provider of additional organic matter for future crop production and a local source of feedstock for biodiesel. However, crop budgets derived from multiple years of data indicate that soil fertility is the major limiting economic factor affecting production. Research has been initiated to improve soil fertility by short and long term approaches to crop production. Long term approaches include changes in land management practices that promote the cultivation of locally adapted nitrogen fixing cover crops. Short term approaches include the modification of application equipment to optimize application of synthetically derived sources of nitrogen. This poster reports on the progress of this research.

Introduction
Rotation crops that provide feedstock oil for biodiesel production offer the potential for creating additional revenue sources for farmers at the same time that large regional truck and bus fleets are seeking more sustainable local biodiesel sources. Biodiesel is a non-petroleum-based diesel fuel produced from the transesterification of vegetable oil or animal fat. Unlike straight vegetable oil, biodiesel has combustion properties very similar to petroleum diesel and can be freely substituted for petroleum diesel in many uses (U.S. Dept. of Energy 2004). In Florida, an enormous market for locally generated biodiesel exists. Since 2004, annual consumption of petroleum diesel in Florida has remained above 1.6 billion gal per year (McDonald and Albanese 2008) while nationally, estimates of U.S. biodiesel production are closer to 700 million gal per year (Anonymous 2008). Locally produced biodiesel feedstocks are less prone to oxidative destabilization (rancidity) caused by lengthy storage and transportation conditions, thus providing a higher quality biodiesel product. Further, large regional fleets are seeking to support the local rural communities and source more sustainable biodiesel feedstock to reduce energy lost in transporting fuel while at the same time lowering their overall carbon footprints

Cultivation of sunflower in Florida as a rotational crop to complement existing horticultural production systems has the potential to provide supplementary revenue streams for rural economies, improve soil fertility, sequester additional carbon from the atmosphere, and provide a local supply of renewable fuel that does not compete with food production. These criteria improve the social sustainability of sunflower production. However, breakeven costs for harvested seed or expelled oil are still to high to sustain local production. This study developed and examined a crop budget to identify variable costs that limit economic production and then initiated research to address the limiting factors.

Methods
Crop budgets for sunflower production were derived from published research and from additional field trials initiated locally. Major factors contributing to the variable costs were identified and prioritized. Field research trials were initiated to develop short- and long-term solutions to reduce variable input costs and make production more economically and environmentally sustainable. Long-term solutions consisted of the identification and integration of indigenous legume varieties into local crop production systems. Short term solutions included the modification of fertilizer formulations, applications and incorportation methods.

Results
Sunflower budget projections and breakeven costs were estimated at several production scales for a yield of 2016 kg/ha with a net return of 869 liters/ha. For an 80 ha production size, breakeven costs were estimated

at $0.30 US 0.4/kg of harvested seed. Examination of the crop budgets indicated that greater than 60% of the variable costs were due to fertilizer applications. Additional field experiments were established to investigate the contribution of an indigenous legume (*Aeschynomene americana*) to soil fertility and to minimize supplemental fertilizer applications through improved technology.

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Soil management for reduce Cd concentration in rice grains

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Abstract
Cadmium contaminated soils have a health and socio-economic impact on people who live in that area. Food safety and quality becomes a social concerning issue. To obtain the information on cadmium accumulated in rice grains, two rice varieties, Khao Dawk Mali 105 (Indica) and Khao' Yipun DOA1 (Japonica) were grown by farmer practice method, irrigation method and soil washing method. The results showed that irrigation and soil washing methods can reduce cadmium concentration in rice grains.

Key Words
Farmer practice, heavy metal, on-site wash, Oryza sativa, rice variety, submerge soil.

Introduction

Rice is the major crop in Thailand and most of Thai consume rice. Thailand produces about 30 million tons of rice per year to be consumed in the country and exported. (Office of Agricultural Economics 2008) Soil contaminated with cadmium causes uptake by plants. Rice contaminated with Cd may cause health and socio-economic impact on people. Guo *et al*. (2007) reported that japonica rice takes up and accumulates less Cd than indica rice. Irrigation is one of the soil management practices for reduce Cd concentration in rice grains (Simmons and Pongsakul 2003). Soil chemical washing was performed in a paddy field in Nagano Prefecture and considerably decreased the Cd concentrations in the rice straw and unpolished rice, from 0.91 and 0.31 mg/kg, respectively, in the unwashed soil to 0.18 and 0.053 mg/kg in the washed soil (Makino 2007).

Hypothesis

Hypothesis 1 In submerged paddy soil sulfate ions are reduced to sulfide resulting in the precipitation of the Cd and Zn minerals and rice will less uptake of Cd.

$$Cd^{2+} + S^{2-} \longrightarrow CdS \qquad (1)$$

Hypothesis 2 After soil washing, Cd concentration in soil will decrease and rice will less uptake of Cd.

$$\text{Soil } Cd^{2+} + M^{2+} \longrightarrow \text{Soil } M^{2+} + Cd^{2+} \qquad (2)$$

Objective

To study Cd uptake by Khao Dawk Mali 105 (Indica) and Khao' Yipun DOA1 (Japonica) by differnder various soil management.

Studied area

A paddy field in Mae Sot District, Tak Province at 47Q 0459779 and 1843130 was selected for the study.

Project duration

The project duration is one year from 2008 to 2009.

Methods

Treatment

Completely randomized design with 5 replications was used for the experiment.

Table 1. Soil management used in the experiment.

No.	Treatment
1. Control FP	Khao Dawk Mali 105 with farmer practice
2. FP2	Khao' Yipun DOA1 with farmer practice
3. RI	Irrigation method for Khao Dawk Mali 105
4. RI2	Irrigation method for Khao' Yipun DOA1
5. SW	Soil washing and follow by Khao Dawk Mali 105 plantation
6. SW2	Soil washing and follow by Yipun DOA1 plantation

Field preparation

FP: farmer practice by flooding the rice field during vegetative growth, reproductive growth and early stage of grain development.

RI: Rice field was flooded every growth stage.

SW: Soil washing with $FeCl_3$ solution.

Figure 1. Field preparation for planting rice (29 April 2008).

Soil and rice grains sampling

Soil samples were collected from 15 random points (0-15 cm depth) in each treatment. The sample were air-dried and ground prior to analysis.

Rice grain samples were collected at physiological maturity from each treatment. All rice panicles were removed and placed in appropriately labeled paper bags. Grain samples were subsequently separated and oven dried at 65ºC for 72 hrs prior to de-hulling and grinding to a fine powder.

Analytical method

Total soil cadmium was determined in a 2 : 1 $HClO_4$: HNO_3 using an open tube digestion method and block digester. Plant samples were digested in 2 : 1 HNO_3 : $HClO_4$ using an open tube digestion technique (Zarcinas *et al*. 1983). Prior to digestion, plant samples were pre-digested overnight at room temperature to avoid excessive reaction on heating. Cadmium concentrations were determined using the Inductive Couple Plasma Emission Spectroscopy (ICP-OES) Perkin Elmer Optima 2100 DV.

Results

Soil characteristics

Soil properties of top soil are listed in Table 2. The soil texture was loam. The pH was 7.7 and electrical conductivity was low. Organic matter was very high. Cation exchange capacity was moderately high according to Soil Survey Division (1972). Plant nutrients were medium or low so fertilizer was applied. The concentration of As, Cu, Pb and Zn were at background level concentrations (Wild, 1993). Cadmium was high and indicated that soil was contaminated by Cd (Table 3).

Table 2. Soil characteristics.

Parameters	Unit	Topsoil (0-15 cm)
1. Texture		Loam
2. pH		7.7
3. OM	%	4.86
4. CEC	cmol/kg	15.8
5. EC	dS/m	0.14
6.Plant nutrient (Extractable)		
P	mg/kg	10.6
K	mg/kg	50.2
Ca	mg/kg	3640
Mg	mg/kg	325
Fe	mg/kg	71
Mn	mg/kg	19
Cu	mg/kg	2.56
Zn	mg/kg	17.6
Heavy metals (Total)		
As	mg/kg	12.6
Cd	mg/kg	5.94
Cu	mg/kg	11.3
Pb	mg/kg	16.0
Zn	mg/kg	202

Table 3. Average concentrations of heavy metals

Metal	Earth's crust (mg/kg)	Soils (mg/kg)	Rocks with highest concentration
As	1.5	0.1-50	shales and clays
Cd	0.1	0.01-2.4	shales and clays
Cu	50	2-250	basic
Pb	14	2-300	granite
Zn	75	10-300	shales and clays

Source: Adapted from Wild (1993)

Cd uptake by rice

Cadmium concentration in rice grains, shoot, root and husk for different treatments are presented in Table 4. The results showed that Cd concentration in Khao Dawk Mali 105 rice grains for the irrigation method and soil washing method was not significantly different. Significant differences were observed between Cd concentrations in rice grains for farmer practice method and the irrigation and soil washing methods. For Khao' Yipun DOA1, significant difference were observed between soil washing method and irrigation and farmer practice methods. Cadmium concentration in Khao Dawk Mali 105 in shoot and husk of soil washing method and irrigation and farmer practice method were significantly differences. Non-significant differences were obtained for irrigation method and soil washing method. Non-significant differences were also obtained for soil washing and irrigation methods and farmer practice method for Khao' Yipun DOA1. Rice roots accumulate high Cd concentration. Khao Dawk Mali 105, significant differences were observed between soil washing method and irrigation and farmer practice method. Significant differences were also observed between irrigation method and farmer practice method. According to result for Khao' Yipun DOA1, significant differences were observed between the irrigation method and soil washing method but non-significant differences were obtained between soil washing method and farmer practice method.

Table 4. Cadmium in rice grains, shoot, root and husk in different treatments.

Soil management	Rice varities	Cadmium concentration (mg/kg)			
		Rice grains	Shoot	Root	Husk
1. Farmer practice	Khao Dawk Mali 105	1.190 a	3.200 a	7.690 a	1.260 a
	Khao' Yipun DOA 1	0.050 d	0.280 b	6.350 b	0.120 b
2. Irrigation	Khao Dawk Mali 105	0.170 c	0.230 b	5.490 b	0.130 b
	Khao' Yipun DOA 1	0.096 d	0.430 b	3.262 c	0.100 b
3. Soil washing	Khao Dawk Mali 105	0.220 b	0.550 b	3.120 c	0.170 b
	Khao' Yipun DOA 1	0.150 c	0.540 b	5.660 b	0.110 b
F-test		**	**	**	**
CV (%)		11.9	30.6	17.7	27.0

Soil management by irrigation method and soil washing method can be used to reduce Cd concentration in rice grains. Cadmium was taken-up and accumulated in rice roots at higher concentration than in rice grain, shoot and husk.

Conclusion

Two rice types Khao Dawk Mali 105 and Khao' Yipun DOA1 was subjected to different soil management in a Cd contaminated soil context: (i) farmer practice, (ii) irrigation and (iii) soil washing method.
Soil management by irrigation and soil washing methods can reduce cadmium concentration in rice grains. Rice takes up and accumulates less Cd as can be explained by the following hypotheses.
Hypothesis 1 In submerged paddy soil sulfate ions are reduced to sulfide resulting in the precipitation of the Cd minerals and rice will uptake less Cd.
Hypothesis 2 After soil washing, Cd concentration in soil will decrease and rice will uptake less Cd.

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Sugarcane crop for biofuel production, demand on soil resource and food security in Brazil

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Abstract
The expansion of agriculture is responsible for major changes of land use in Brazil. There is a great potential for growth of the ethanol production in Brazil, due to growing demands from both domestic and international markets. Sugarcane is the raw material for sugar and ethanol production. We present a sugarcane land expansion scenario for the next 10 years (2008-2017); it takes into account the market forces (supply and demand). The total land required for the sugarcane cropping will be around 17 million hectares in 2017. This sugarcane expansion is planned to occur in substitution of pasture and degraded lands. There are approximately 37 million ha of pasture area located in suitable zones for sugarcane cropping in Brazil. The concentration and extension of sugarcane cropped areas in the center-south regions of Brazil is associated with potential impacts to the environment, society, and economy. Thus, considering the dynamic interactions between the global effects of land use environmental impacts, and demands of agroenergy production and food security, it is important to implement sustainable effective regulating policies targeting sugarcane crop expansion and to carry out ex ante evaluations of the impacts derived from the expansion of sugarcane crops in different regional scenarios.

Key Words
Ethanol, soil resource, sustainability impacts, policy intervention.

Introduction
The expansion of agriculture is responsible for major changes of land use in Brazil. As a response mainly to market demands, new agricultural frontiers have been gaining ground in the country. Over the past 15 years, the growth of Brazilian agricultural exports increased by 6% per year and there are opportunities for this growth to continue at rates equal or greater than this (CONAB 2007). Brazilian livestock and agricultural production are large and diverse. The total land area of the country is 845 million hectares (Mha), of which approximately 260 Mha are under agriculture and pastoral use (FAO 2004). The area of Brazilian land occupied by agriculture was approximately 60 Mha, of which about 22 Mha with soybeans, 12 Mha by corn, and nearly 7 Mha by sugarcane, while the area under pasture was about 200 Mha in the 2007/08 season (IBGE 2008). The country has the second largest bovine herd in the world, after India, but the standard beef cattle production systems are based on animals feeding on open air pasture conditions, only a small amount of animals, around 2.7 million, that corresponded to 6.7% of the slaughtered animals, were fed in feedlots in 2008 (Ferraz and de Felicio 2009).

Projections made by the Brazilian Ministry of Agriculture, Livestock, and Food Supply (MAPA) state that Brazil would soon become the world leader in the production of biofuels (MAPA 2008). According to MAPA (2007) the amount of agroenergy crops cultivated in the country can still expand, since 91 million hectares of land are available for agricultural expansion, provided the legal and normative requirements related to land use and occupation are complied with. Sugarcane is the raw material for both sugar and ethanol production. Among all raw materials used to produce ethanol, sugarcane presents the highest yield and the lowest cost, resulting in lower production costs to the country (MAPA 2007). Sugarcane cropping is concentrated in the Center-South regions of the country and the state of São Paulo contains around 60% of the Brazilian sugarcane crops, occupying about 3.8 Mha (CONAB 2008).

The expansion of sugarcane cropped areas will occur mainly as a result of the implementation of new sugar and ethanol industrial plants and the growth of existing industrial plants (Macedo 2002). Sugarcane has a very high impact in the changes of soil use; therefore the formulation of public policies regarding agroecological zoning should be the base in each State in order to expand sugarcane crops in a sustainable way in the country.

This paper presents a sugarcane land expansion scenario for ethanol production for the 2008-2017 period, based on available data regarding ethanol demand and supply in Brazil, formulated by the Brazilian Energy Research Corporation (EPE 2008). Based on the sugarcane land expansion scenario for ethanol produce, we compared the land demand for sugarcane production until 2017 and the currently available land for food production in Brazil, and present an initial discussion about the impacts of land use to energy production and the food security in the country. Even if there is, in Brazil, availability of land for both energy production and to meet the demands of future food production, it is necessary to safeguard the natural resources, and in some cases even increase the environmental quality of agricultural development, in order to contribute to global sustainability.

Methods

The land demand scenario for sugarcane crop aiming at ethanol production was developed considering the bioethanol supply and demand scenarios for Brazil. These were obtained from the document National Supply and Demand Projections for 2008-2017, published by the Energy Research Company, as part of the Decadal Energy Plan of the Brazilian Government (EPE 2008).

For the elaboration of the scenarios the premises adopted were: a tonelade (ton) of sugarcane produces in average 81.6 liters of ethanol; the average physical yield of sugarcane varied linearly from 81.4 tons/ha in 2008 to 86.2 tons/ha in 2017. The productivity value assumed in 2008 corresponds to the average Brazilian productivity in the 2007/08 seasons and the 2017 value assumes that average Brazilian productivity in 2017 will be equal to the average productivity of sugarcane in the state of São Paulo in the 2007/08 seasons, the state with the highest physical productivity in the country (Table 1). In order to develop the sugarcane expansion scenario for ethanol production in Brazil, we first estimated the amount of sugarcane, in tons, needed to produce additional ethanol to attend the ethanol supply predict by demand andsupply scenarios (EPE 2008). We considered a linear increase in the liters of ethanol produced by ton of sugarcane and in the physical productivity of cane in the period 2008/2017. Then we calculated the area needed to produce the sugarcane in this period. To calculate the amount of sugarcane by liter of ethanol produced we considered the industrial returns that are measured by the amount of TRS (Total Recoverable Sugar) obtained per ton of sugarcane. This index is directly related to climate behavior, which interferes in the level of sucrose concentration achieved by the plant and offers an indication of which regions have the best environmental and climatic conditions for growing this type of crop.

Table 1 shows the profile of sugarcane and ethanol production in the 2007/2008 seasons, including the average TRS, the amount of ethanol produced per ton of sugarcane and the average productivity for the Brazilian Center/South. (It is composed of following states: São Paulo, Minas Gerais, Rio de Janeiro, Espírito Santo in the southeast region and Paraná in the south region and Mato Grosso, Mato Grosso do Sul, Goiás in the central-west region) and for the North/Northeast (Acre, Amapá, Amazonas, Pará, Rondônia, Roraima and Tocantins - North region and Maranhão, Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia-Northeast region).

Table 1. Area sugarcane (thousand hectare), Production (thousand tonelade), Total Recoverable Sugar –TRS (Kg TRS/ tonelade sugarcane), quantity of ethanol produced per ton of sugarcane (liter ethanol/ tonelade sugarcane) and average physical productivity (tonelade sugarcane/ hectare) for the Center/South and North/Northeast regions and the Brazilian average in 2007/2008 seasons.

Region	Area sugarcane 2007/08 season (000s ha)	Production of Sugarcane (000s ton)	TRS (kg/ton)	Ethanol production (liter/ton)	Average Productivity (ton/ha)
Center /South	5,996	505,925	141.7	82.2	84.3
North /Northeast	1,075	65,885	133.8	77.6	65.8
São Paulo State	3,851	342,911	142.3	82.5	86.2
Brazil	7,071	571,810	140.7	81.6	81.4

Source: CONAB (2008).

The Center/South regions, in comparison with the North/Northeast regions, present a higher edaphoclimatic for sugarcane cropping, concentrated in the State of São Paulo (Table 1).

Results

The expansion scenario of sugarcane crops in Brazil, based on the EPE demand and supply scenarios, is shown in Table 2.

Table 2. Projections of ethanol supply, sugarcane production associated land requirement for cultivation, in Brazil, 2008 – 2017

Year	Ethanol Supply (Billion liter)	Sugarcane demand (000s ton)	Potential yield (ton/ha)	Total land required for ethanol production (000s ha)	Additional land required for ethanol production (000s ha)
2008	25.1	307.598	81.9	3,779	-
2009	29.5	361.121	82.4	4,409	630
2010	32.8	401.076	82.8	4,867	458
2011	36.9	450.715	83.3	5,443	576
2012	41.6	507.565	83.8	6,093	650
2013	46.5	566.728	84.3	6,763	670
2014	50.8	618.456	84.8	7,336	574
2015	55.0	668.856	85.2	7,887	551
2016	59.1	717.930	85.7	8,426	539
2017	63.9	775.391	86.2	9,048	621

The expansion scenario of sugarcane cultivation for ethanol production in Brazil starts from approximately 3.8 million ha (about half of total sugarcane cropping area, including crops directed towards sugar production), in 2008 (CONAB 2008). In 2017, about 9 million ha will be needed in order to attend to the ethanol supply forecasted by EPE (Table 2). If we consider crops to produce sugar, this figure rises to approximately 17 millions hectares. This scenario produced a projection of the area demanded for bioethanol sugarcane crop production in Brazil, not considering any political intervention, taking into account solely market forces (supply and demand).

Due to the favorable environmental and climatic conditions and the greater variety and quality of genetic material for sugarcane crop, around 90% of the new areas of production and most of the new production units will be built in the Center-south regions of the country. This region, which the states have wet summers and dry winters, are the most productive regions for the production of ethanol, presenting a high level of sucrose concentration as measured by TRS. The Northeast region, with warmer temperatures and a low thermal amplitude over the year, and the North (including the Amazon), which is a very warm and wet region, have much lower sugar and ethanol returns than the other states mentioned.

Conclusion

As mentioned, in Brazil, the amount of land available to the expansion of agricultural crops, including sugarcane, with no need for any deforestation, is significantly high, considering there are 91 million ha of suitable land, including degraded pastures and abandoned land. Based on EPE data, we estimate that 17 million hectares of land will be needed to attend the demand for ethanol production in 2017. This expansion could occur under current pasture areas. This would require the adoption of more sustainable and intensive systems of livestock production (more units per hectare), higher investments in technological development aiming at enhancing yields, and genetic improvement and recovery of pastures.

The Sugarcane Agroecologic Zoning – ZAECANA (Manzatto et al 2009) is an environmental policy instrument, developed within national development plans and programs that regulate agricultural growth in Brazil. It guides sugarcane crop expansion in the Brazilian territory, defining the spatial distribution of areas suitable and unsuitable for sugarcane crop establishment. The national sugarcane zoning determines the areas and locations of regions allowed receiving governmental incentives for sugarcane cultivation and ethanol plants establishments. According to the ZAE CANA, there are approximately 64 million ha under pasture and agriculture that area suitable for sugarcane cropping in Brazil, most of them under pasture (37 million ha). Currently, research efforts are being dedicated to map the degraded lands in Brazil, so that the future demand for sugarcane cultivation is directed to these areas, guaranteeing that the new plantations will not compete with the soil or water resources needed for food production, considering the growing needs of the growing world population.

A great deal of the impacts derived from sugarcane crops in Brazil is due to the concentration and extension of sugarcane monoculture crops in the Center-South regions of Brazil can result in significant negative environmental impacts of an increase in the extension land occupied by monocultural plantations of sugarcane . The main concerns are the loss of habitat and biodiversity, the offset or worsening of, such as: enhanced erosive processes, with consequent soil and water losses from the system due to bad management, greater water and soil nutrients demands,; imbalanced hydrological cycles; changes in fauna dynamics, pesticide contamination of soil and water, and biodiversity and habitat loss (De Maria 1999). Therefore, in addition to territorial ordinance policy instruments, such as agroecologic zoning and preferential funding schemes, governmental regulations aiming at sustainable soil, water and crop management are necessary to prevent the offset of land degradation processes associated with sugarcane plantations expansion in Brazil.

Thus, from the perspective of assembling the land use, agroenergy production and food security issues, resolving the problem of the added demand for planted area is not enough, Federal and State governmental regulations and policy instruments are necessary to regulate sugarcane crop expansion in a sustainable way and more research is needed to develop tools for land use change sustainability impact evaluations under different regional scenarios.

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Water quality effects of crop residue removal for cellulosic ethanol production

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Abstract
Crop residues have been identified as a prime feedstock for large-scale cellulosic ethanol production. Therefore, understanding the impacts of widespread residue harvest on soil and environment is essential to establish soil-specific residue harvest rates. We assessed the effects of variable levels of corn residue removal on runoff and soil erosion on a regional scale across three locations (Colby, Hugoton, and Ottawa) in Kansas. Five residue treatments that consisted of removing 0, 25, 50, 75, and 100% of corn residue after harvest were studied for losses of runoff, sediment, soil organic carbon (SOC), total N and P, NO_3-N, NH_4-N, and PO_4-P. Simulated rainfall at a rate of 76.2 mm/h in Colby and Hugoton, and 91.4 mm/h in Ottawa was applied for 30 min. Results of this regional study showed that runoff volume, SOC, and total N and P concentrations increased with increase in residue removal at all locations. In contrast, NO_3-N, NH_4-N, and PO_4-P concentrations in runoff increased with decrease in residue removal rate, most likely due to nutrient leaching from residues. Our results suggest that high rates of residue removal for cellulosic ethanol production will increase sediment, SOC, and total nutrient loss in runoff, potentially resulting in soil and environmental degradation.

Key words
Stover, bioenergy, eutrofication, fertility, management, *Zea mays* L.

Introduction

There exists a rising need for the development of alternative fuels from renewable sources in order to reduce dependence on non-renewable energy sources, mitigate net emissions of greenhouse gases, and provide energy to an ever-increasing population (Energy Information Administration 2009). With advances in cellulosic conversion technology, plant biomaterial such as crop residues can now be efficiently used as a feedstock for the production of cellulosic ethanol (Gray *et al.* 2006). Residue removal, however, can accelerate soil erosion, resulting in the transport of non-point source (NPS) pollutants into neighboring waterways (Blanco-Canqui and Lal 2009). While complete removal of crop residues from agricultural fields for biofuel production may jeopardize crop productivity as well as soil and environmental quality, a partial removal of residues without adverse effects may be possible in some soils. To date, experimental data on the permissible levels of corn residue removal are limited. Studies on a regional scale are needed to determine soil-specific residue removal rates that will minimize the erosion of soil, organic carbon, and nutrients from agricultural fields, thus limiting the extent of soil and environmental degradation. Thus, the objectives of this study were to determine the effects of variable levels of crop residue removal on losses of sediment, organic carbon, total nitrogen (N) and phosphorus (P), nitrate (NO_3-N), ammonium (NH_4-N), and phosphate (PO_4-P) in runoff from three different locations in Kansas.

Materials and Methods

Site and treatment descriptions

This study, initiated in March 2009, was performed on three contrasting sites in Kansas including (1) Northwest Research Extension Center in Colby, (2) a private producer's field near Hugoton, and (3) East Central Experiment Field in Ottawa. These sites differ in soil texture, climate, and management (Table 1). A randomized complete block design with five treatments was replicated three times, resulting in 15 plots of 6 x 6 m that were laid out at each site. The five treatments consisted of removing 0, 25, 50, 75, and 100% of the corn residue after harvest. Corn residue is redistributed following harvest at each location. Percent residue removal is estimated by dividing the plots into quadrants, raking the appropriate residue amount off of each plot, and thoroughly redistributing the remaining residue to ensure an even cover. Corn was planted at all sites in May 2009. Plots were demarcated using colored flags placed at the corners of each plot. Two sites (Ottawa and Colby) were managed under no-till while the site at Hugoton was under strip-till.

Additionally, the site in Ottawa is rain-fed, while the sites in Colby and Hugoton are under center-pivot irrigation systems. All sites had slopes ≤ 3%.

Table 1. Soil, climate, and management characteristics of the three study sites

Location	Management	Avg. annual precipitation (cm)	Soil series	Taxonomic classification
Colby	No-till continuous corn Irrigated	47.0	Ulysses silt loam	Fine-silty, mixed, superactive, mesic Aridic Haplustolls
Hugoton	Strip-till continuous corn Irrigated	45.7	Hugoton loam	Fine-silty, mixed, superactive, mesic Aridic Argiustolls
Ottawa	No-till continuous corn Rain-fed	81.3	Woodson silt loam	Fine, smectitic, thermic Abruptic Argiaquolls

Rainfall simulation

Rainfall simulation was conducted in the spring of 2010 to determine runoff, sediment, organic carbon and nutrient losses from all treatment plots across the three study sites. A rainfall simulator with a 30WSQ stainless steel nozzle (Teejet Corp., Dillsburg, PA; Miller 1987) inside an aluminum frame applied rain on 2.5 m² runoff subplots from a 2.5 m height. Plastic tarps were used around the simulator to reduce wind influence on the trajectory of raindrops. Water was supplied to the simulator from a 3,785 L tank through the use of an electric pump. Dry and wet-runs were performed in each plot. Dry runs were done 24 h before wet runs in order to ensure uniform antecedent soil moisture in all treatment plots. Simulated rainfall was applied for 30 minutes at an intensity of 91.4 mm/h in Ottawa, and 76.2 mm/h in Colby and Hugoton. These intensities represent storms with a 5 yr return period for the three locations.

Runoff subplots were bordered with 0.5 cm thick steel plates inserted into the soil to a depth of 5 cm. A V-shaped runoff collector was installed at the downslope end of the plots to direct runoff into graduated buckets inserted in collection pits. The runoff collectors and collection pits were covered during simulations to avoid direct collection of rainfall. Runoff was collected separately in 10 min intervals after initiation of rainfall, resulting in 3 large samples for each 30 min simulation. Three subsamples of runoff from each time interval (0-10, 10-20, and 20-30 min) were collected for the analysis of sediment concentration, sediment-associated-SOC, and nutrients, respectively.

Collected runoff was stirred to ensure the suspension of sediments, and a 1 L subsample was taken for sediment concentration determination. Two more subsamples were taken for chemical analysis: a 100 mL unfiltered sample for total N and P, and a separate 15 mL sample passed through a 0.45 µm filter for NO_3-N, NH_4-N, and PO_4-P determination. The samples were placed on ice in an insulated cooler, transported to the lab, and analyzed within 1 week. Sediment was determined gravimetrically by oven drying runoff subsamples at 60°C, in accord with Blanco-Canqui *et al.* (2004). The oven-dried sediment mass was used to calculate sediment loss (in g/m²) for each plot. SOC content of sediment load was determined by the dry combustion method (Nelson and Sommers 1996). Standard chemical analyses were used for nutrient determination. All data were analyzed using a one-way ANOVA model with residue removal rate as the treatment (SAS Institute 2008). Differences between means were tested using a protected LSD at the 0.05 probability level (SAS Institute 2008).

Results

Runoff volume, sediment load, and organic C

Preliminary results from this study suggest that runoff volume is largely influenced by residue harvest. On average, runoff depth increased from 1.40 mm with 0% removal, to 18.8 mm with 100% removal in Colby. In a similar study, Blanco-Canqui *et al.* (2009) found that runoff volume and sediment load tended to increase with increase in residue removal from no-till wheat plots in Kansas. Compared to 0% removal treatments, sediment loss increased threefold with residue removal rates as low as 50% (Blanco-Canqui *et al.* 2009). This is in agreement with results observed by Lindstrom (1986) with no-till corn in Minnesota. Blanco-Canqui *et al.* (2009) also observed increased SOC loss in sediment as residue removal increased, with a fourfold increase in SOC loss at 75% removal when compared to 0% residue removal treatments.

Total N and P

Blanco-Canqui *et al.* (2009) observed significant losses of total N and P with residue removal levels greater than 75%. Likewise, Lindstrom (1986) found that concentrations of N, P, and K in sediment contained in runoff decreased with decrease in residue removal rate. In both cases, the losses of total N and P were positively correlated with sediment loss.

NO_3-N, NH_4-N, and PO_4-P

No significant impacts of residue removal on NO_3-N, NH_4-N, and PO_4-P concentrations in runoff water from no-till plots were observed by Blanco-Canqui *et al.* (2009). However, preliminary results from the current study suggest that concentrations of NH_4-N, NO_3-N, and PO_4-P in runoff water may tend to increase with decreased residue removal rate. These results can be explained partially by the longer contact time between water and residues, and the increased leaching of nutrients from residues at lower residue removal rates (Schreiber 1999).

Discussion and conclusion

Crop residues play an integral role in minimizing soil erosion and the transport of NPS pollutants into neighboring waterways. Residues prevent soil crust formation and enhance infiltration by shielding the soil surface from the impact of raindrops. Adequate residue cover, therefore, is necessary in order to minimize runoff and limit losses of sediment, SOC, and nutrients from the soil. Results from this study suggest that on certain soils, relatively low levels of residue removal may substantially increase soil erosion, losses of NPS pollutants into surface water, and decrease soil fertility. Further investigation of residue removal in a wide variety of soils, crops, and climates are needed in order to better determine threshold removal levels on a regional scale.

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Carbon sequestration potential in soil and biomass of *Jatropha curcas*

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Abstract
A study was carried out to determine the potential of *Jatropha curcas*, a biofuel crop to sequester carbon by measuring how litterfall, biomass production and canopy photosynthesis rate can offset soil respiration. Litterfall production and its decomposability was monitored monthly for 10 months, biomass production was determined through destructive harvesting while canopy photosynthesis rate and soil respiration was measured using a portable photosynthesis meter system and an automated soil CO_2 flux system, respectively. Biomass of a 32-month old *Jatropha curcas* sequestered 13.0 Mg C/ha, while 2-year old *Jatropha curcas* had a canopy photosynthesis rate of 29.59 µmol/m/s. The combination of these two parameters offsets emission from soil respiration that ranged between 0.84 to 1.04µmol/m/s. Litterfall despite being highly decomposable did not contribute to soil total carbon.

Key Words
Carbon sequestration, *Jatropha curcas*, biomass production, litterfall production, canopy photosynthesis rate, soil respiration.

Intoduction
Production of biofuel from crops has raised many issues mainly on the ethics of using food as the raw ingredient for biofuel production and the extent of environmental friendly biofuel in terms of greenhouse gases reduction. Consumption of energy to produce biofuel releases nearly as much carbon dioxide (CO_2) to the atmosphere as burning conventional fuel from petroleum and coal (Bourne 2007). The main advantage of biofuel in terms of suppressing the current rate of CO_2 released to the atmosphere lies in the natural mechanism of plants in assimilating CO_2 during photosynthesis as its structural material (i.e. biomass). Assimilated CO_2 in plant biomass will in turn be transformed into stable organic matter (i.e. humus) after litterfall and sloughed root decomposition in the soil returning converted CO_2 in the form of carbon (C) to soil. However, cultivation practices of biofuel crops involving soil preparation are causing rapid decomposition of soil organic matter releasing CO_2 back into the atmosphere (Robert 2001). The present study aims to determine the balance between CO_2 released to the atmosphere through soil respiration and CO_2 assimilated through photosynthesis of *Jatropha curcas*, a perennial biofuel crop. The study also aims to quantify biomass in terms of dry matter production and annual litterfall by *Jatropha curcas* and its contribution to increased soil C.

Methods
Study site
The study was conducted at University Agriculture Park, Plot D, UPM, Serdang, Selangor, Malaysia. Soil at the study site is a Plinthic Paleudult of the Batu Lapan series. An area of one hectare at the study site was planted with *Jatropha curcas* of different ages at a planting distance of 2x3m from three months old seedlings.

Litterfall collection and chemical analysis
Litterfall was collected from nine randomly chosen *Jatropha* trees where litter traps made of nylon fishing nets were placed under the canopy of each tree. The size of each net was approximately $4m^2$. Litterfall was removed from the litter trap and collected monthly beginning from July 2008 until April 2009. The collected litterfall was oven-dried at 60^oC and ground to 1mm using a cutting mill. Total C content of the litterfall was analyzed using a carbon analyzer (LECO CR-412). Total nitrogen content was determined using the Kjeldahl method. A ratio of carbon to nitrogen (C:N) on a weight basis was then derived based on the results.

Biomass dry weight determination and carbon content analysis
Three *Jatropha curcas* trees were selected from three different ages; 10, 17 and 32 months for destructive

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sampling. The trees were sawn down at the base of the stem closest to the ground. The fresh weight of the above ground part of the trees was directly determined. The leaves were later removed and separately weighed. The belowground (root) portion of the trees was excavated using a backhoe and soil particles attached to the roots were removed and the roots were then immediately weighed. All parts of the tree were subsampled and oven dried to a constant weight for moisture determination. The samples were later ground to 2mm to be analyzed for total C content using a carbon analyzer. Dry matter of the whole tree was derived by correcting the fresh weight of each tree for its moisture content. The mass of C present in each tree was then calculated.

Leaf photosynthesis and leaf area index measurement
Leaf photosynthesis rate was measured every fortnight in September and October 2009 using a portable photosynthesis meter system (LI-6400XT, Li-Cor Biosciences). Photosynthesis was measured three hours after sunrise on three trees of two different ages (one and two years old). Fully matured leaves from each tree were selected for photosynthesis measurement. For each tree that was measured for its photosynthesis rate, its leaf area index (LAI) was measured using a leaf canopy analyzer (LAI-2000, Li-Cor Biosciences).

Soil CO_2 flux
Soil CO_2 flux was measured weekly in September and October 2009 using an automated soil CO_2 flux system (LI-8100, Li-Cor Biosciences) under the canopy of three randomly chosen trees.

Soil total carbon content
Soil was sampled on the three different locations at the study site; uncultivated section of the site (N), under the littertrap (UL) and under tree canopy without a littertrap placed under it (WL) at two different depths (0-20 and 20-40cm). All the sampled soils were air-dried, ground and sieved to 1mm and analyzed for total carbon content using a carbon analyzer (LECO CR-412).

Statistical analysis
Analysis of variance was conducted to test the effect of age on biomass dry matter production and its carbon content and for sampling depth and location on soil total carbon. All means were compared using Tukey's test.

Results and discussion
Literfall
Litterfall production showed no consistent trend with time as the mass of litterfall fluctuated during the study period (Figure 1) ranging from 62.59 to 183.52kg/ha month^{-1}. Despite the inconsistency of litterfall mass, litterfall C:N ratio remained fairly constant throughout the study period ranging from 17:1 to 21:1. The C:N range of the litterfall indicates that litterfall of *Jatropha curcas* was highly decomposable as plant materials with C:N less than 20:1 decompose rapidly (Heal et al., 1997). The contribution of C to soil through litterfall decomposition in the present study was determined based on differences in soil total C sampled at different sites (N, UL and WL), which will be discussed later.

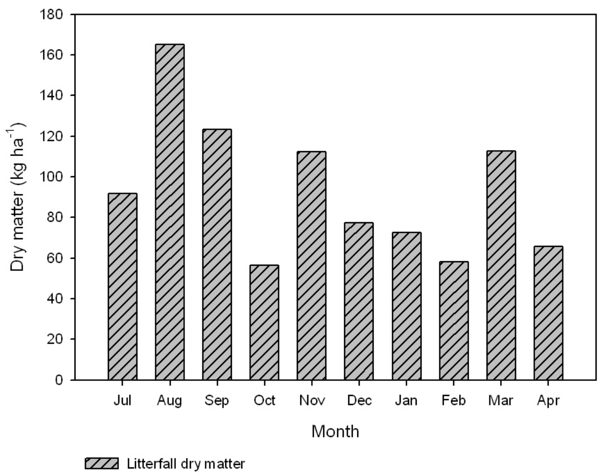

Figure 1. Dry mass of litterfall for each month

Biomass production

A rapid increase of dry weight was observed in the aboveground part of the tree (excluding leaves) compared to leaves and root where a more gradual increase in dry weight was observed (Figure 2). Higher biomass production of *Jatropha curcas* from the aboveground portion of the tree compared to the belowground portion could be explained by the ability of the tree to adapt to drought without having to extend its root system to obtain water (Heller, 1996; Ericsson et al., 1996). There was an increase of C in biomass during a 12-month period with an increase of mean whole tree (aboveground and belowground) C of 11.53Mg C/ha (Table 1). The results from both Figure 2 and Table 1 indicate that *Jatropha curcas* stores substantial amounts of C but this is predominantly stored in the aboveground portion of the tree compared to other parts.

Table 1. Mean dry weight (± standard error) of different parts of *Jatropha curcas*. Means with different alphabets are significantly different using Tukey's test at p<0.05.

Age (month)	Plant part						Total C in biomass (Mg/ha)
	Aboveground		Belowground		Leaves		
	C content (%)	C in biomass (Mg/ha)	C content (%)	C in biomass (Mg/ha)	C content (%)	C in biomass (Mg/ha)	
32	46.90 ± 0.27a	9.91± 0.70a	46.88a*	3.09 ± 0.042a	46.57 ± 0.56a	1.62 ± 0.33a	13.00 ± 1.06a#
17	46.75 ± 0.36a	5.14 ± 0.42b	46.76b*	1.81± 0.09b	46.01 ± 0.42a	0.78 ± 0.06ab	6.95 ± 0.51b#
10	46.23 ± 0.27a	0.95 ± 0.07c	44.59c*	0.52 ± 0.02c	45.64 ± 0.20a	0.37 ± 0.19b	1.47 ± 0.19c#

*Only one replicate was determined for C content
#Excluding leaves

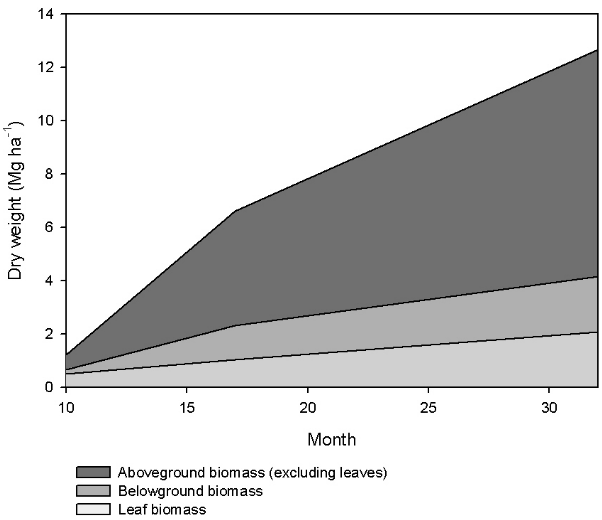

Figure 2. Biomass allocation to various parts of *Jatropha curcas.*

Canopy photosynthesis

Mean leaf photosynthesis (± standard error) for one year and two year old trees were 7.24±0.91 and 8.04±1.38µmol/m/s respectively. Based on the mean LAI for one year old trees of 0.54 and mean LAI for two years old trees of 0.92 and assuming the canopy covers a ground area of 4m^2, canopy photosynthesis rate for a one year old and two years old tree would be 15.64µmol/m/s and 29.59µmol/m/s respectively. The actual photosynthesis rate however would be less than the calculated rate as the calculated rate was based on the photosynthesis rate of fully matured leaves. However, the number of fully matured leaves on a *Jatropha curcas* tree at a given time is unknown.

Soil CO_2 flux

Soil CO_2 flux showed no significant differences between the different time of the month when the measurement was carried out ranging from 0.84 to 1.04µmol/m/s. Based on the consistency of our data, for the purpose of comparison with canopy photosynthesis, we assumed that the soil CO_2 flux and canopy photosynthesis rate will remain constant within this range throughout the year.

Soil total carbon

At depths of 0-20 and 20-40cm, there were no significant differences of soil total C at different position in the field where soils were sampled. The results indicated that there was no addition to soil total C through the decomposition of litterfall. However, the labile portion of the total carbon has to be analyzed before ruling out the contribution of litterfall to any increase in soil C. No differences that were observed between the uncultivated section and the parts of the field that was cultivated could be explained by the study site that was regularly ploughed before the site was planted with *Jatropha curcas* therefore obtaining a reference sample of the site that was naturally undisturbed to determine its initial C content was not possible.

Table 2. Mean mass of soil carbon (± standard error) at different sampling points. Means with same latter are not significantly different using Tukey's test at p<0.05.

	C mass in soil (Mg/ha)		
Sampling depth (cm)	Uncultivated section	With littertrap	Without littertrap
0-20	36.79±4.54a	37.99±1.03a	36.79±3.34a
20-40	28.41±0.66a	28.22±0.84a	30.73±5.03a

Conclusion

Although litterfall production of *Jatropha curcas* does not indicate any addition to soil total C, sequestration of C by *Jatropha curcas* is visible in its biomass production through photosynthesis. The results from the present study showed that assimilation of CO_2 through canopy photosynthesis rate of one year and two years old trees of 15.64µmol/m/s and 29.59µmol/m/s respectively exceeds the amount of CO_2 released by soil respiration at rates of between 0.84 to 1.04µmol/m/s. Nevertheless, the results obtained are still inconclusive of the actual C sequestration rate of *Jatropha curcas* as plant photosynthesis is inactive at night and plant and soil respiration during the night also has to be included to get the actual picture on the capability of *Jatropha curcas* to sequester C.

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