Trends in productivity and nutrient dynamics under improved soil nutrient management techniques for rice in the rainfed lowlands of Cambodia

Seng Vang[A], Lim Vanndy[A], KhokPros[A], Richard Bell[B] and Peter White[C]

[A]Soil and Water Sciences Division, CARDI, Phnom Penh, Cambodia, Email vseng@cardi.org.kh
[B]School of Environmental Science, Murdoch University, Perth, Western Australia, Email R.Bell@murdoch.edu.au
[C]Department of Agriculture and Food, Perth, Western Australia, Email Peter.White@agric.wa.gov.au

Abstract
Increasing rice yields in rainfed lowlands of Cambodia relies on better understanding of balanced nutrition and matching crop demand with nutrient supply. A field experiment was conducted for 6 successive seasons on a sandy soil (*Plinthustalf*) to assess the effects on soil properties, rice yield and profits under organic (O), inorganic (I), and combined organic and inorganic (OI) supply systems. In each system, there were four nutrient regimes: application once to the first crop (FR1); application to the first wet season crop only and land fallow in the dry season (FR2); applied to every wet season crop (FR3), and; applied to every wet and dry season crop (FR4). Composted cow manure was applied at 5 t/ha, whereas N, P and K were applied at recommended rates. Under the O system, the yield accumulated after 6 crops was5.9, 5.0, 8.7, and 11.7 t/ha for FR1, R2, FR3, and FR4 regimes, respectively. Under I system, yields increased by 49-59 %. Under the OI system, the cumulative yields were 8.6, 7.3, 14.3, and 16.3 t/ha for FR1, FR2, FR3, and FR4 regimes, respectively. After 6 crops, soil pH, soil organic C and exchangeable K increased, there was no change in soil N, and extractable P increased with the OI system. The combined OI system was the most productive and profitable nutrient management approach.

Key Words
Lowland rice soil fertility, organic and inorganic fertilizers, grain quality, economics of fertilizer use.

Introduction
The cultivated rice area in Cambodia has increased from 2.16 M ha in 2000 to 2.59 M ha in 2007 which included 88% rainfed lowland areas, and the average grain yield has increased from 1.9 to 2.6 t/ha over the same period (NIS 2008). Most soils in the rainfed lowlands of Cambodia are infertile and plant growth is generally limited by poor soil fertility together with fluctuating soil water regimes (Seng *et al*. 2004). Two-thirds of them are derived from old (Pleistocene) alluvial/colluvial deposits and 28 % from recent alluvial deposits (White *et al*. 1997). The common lowland rice soils which comprise 39 % of the rice-growing soils have very sandy surface horizons with varying depth of sand which extends deeper than 1 m in some soils (Seng *et al*. 2005). One third of the rice growing soils are strongly acidic under oxic conditions. Apart from the recent alluvial soils which have > 23 % clay and the highest CEC, exchangeable K and Olsen P, all other soils contain very low levels of exchangeable K and Olsen P (Bell and Seng 2004). Strong responses to N are generally reported in most rice soils (Seng *et al*. 2001).On the sandy soils (Prey Khmer, and Prateah Lang soils), N alone either has no effect on yield or decreases it (Seng *et al*. 2001). On most soils, responses to P alone may be obtained although strongest responses generally require N and P, and in some soils K and S fertilizers are also required. Soil physical properties are often limiting for tillage, and several profile types have sub-soil features that limit root growth. Previous research showed that the growth and yield of rainfed lowland rice in Cambodia is restricted by inadequate supplies of N, P and K (Seng *et al*. 2001). Cambodia has the lowest average fertilizer application rate for rice crop, 20-9-5 kg N-P-K/ha/year, compared to neighbouring countries (EIC 2006). These rates are lower than the recommended rates for lowland rice soils (Seng *et al*. 2001). Many farmers have insufficient money to buy the recommended rates of fertilizer or fertilise at conservative rates because of uncertain rainfall and concerns about sustainable soil management with recommended rates. Increasing and stabilizing rice yields in rainfed lowlands of Cambodia relies heavily on better understanding of balanced nutrition and matching crop demand with soil nutrient supply dynamics that should improve nutrient use efficiency, limit environmental damage and increase farming profit. A study was conducted to assess the productivity trend of lowland rice soil by measuring rice yield, soil properties, and profits under three soil nutrient management systems viz: organic, inorganic, and combined organic and inorganic supply systems. The main objective of the study was to determine the effects of organic and inorganic fertilizer application regimes on rice yield, soil chemical properties, grain quality, and profit of fertilizer use.

Methods

Experimental design and statistical analysis

Field experiments were conducted in CARDI research field (1268857N, 479766E) on a rainfed lowland sandy soil (*Plinthustalf*) under three soil nutrient management systems (SNMS) *viz*: organic (O), inorganic (I), and combined organic and inorganic (OI) supply systems. In each system, there were four fertilizer regimes: application once to the first crop but the following dry and wet season crops received no added nutrients (FR1); nutrient application to the first wet season crop only and land fallow in the dry season (FR2); nutrients applied to every wet season crop (FR3); and nutrients applied to every wet and dry season crop (FR4). The experiment was designed in a randomized complete block design with 3 replicates and 12 treatments (3 SNMS x 4 nutrient regimes). An early-maturing, aromatic rice variety (110 days), *cv*. Sen Pidao was grown throughout the experiments. Plot size was 5 x 5 m, 2-3 twenty-day-old seedlings were transplanted per hill at 20 x 20 cm spacing. Rice grain yields, soil chemical properties, grain nutrient concentrations, and profits from fertilizer use were assessed. Data were statistically analysed using CropStat7.2 for Windows (IRRI 2007). Only data of soil properties, grain yield, and profits of fertilizer use are presented while grain nutrient concentrations are also discussed.

Manure and fertilizer application

Composted cow manure was applied at 5 t/ha, whereas N, P and K (as NH_4-N, P_2O_5 and K_2O) were applied (kg/ha) at 50-25-30 in the wet season, and 100-50-60 in the dry season. Urea (46% N), DAP (18% N, 46% P_2O_5) and muriate of potash (50% K) were used for the experiment. These rates were converted to the equivalent amount per plot. The composted cow manure used for the experiment contained 0.4% N, 193 mg/kg of extractable P, and 493 mg/kg of extractable K. This would provide the equivalent of 20 kg N, 2.2 kg of P_2O_5, and 3 kg of K_2O per hectare. Cow manure was incorporated 10-15 days before transplanting. All P and K plus 50% of N (adjusted with amount in DAP) were applied basally, a day prior to transplanting. The remainder 50% of N was top-dressed as urea at panicle initiation.

Cropping sequences

There were 6 successive seasons (3 wet seasons-WS, 3 dry seasons-DS) from 2005 wet season to 2008 dry season. The first WS crop (C1) was transplanted into puddled soil in September and harvested in late November, 2005. It was not necessary to compare the effect of fertilizer regimes under each SNMS in the first crop since they received the same amount of added fertilizer nutrients. The first DS crop (C2) was transplanted in March and harvested in May, 2006. The second WS crop (C3) was transplanted in August and harvested in October, 2006. The second DS crop (C4) was transplanted in February and harvested in May, 2007. The third WS crop (C5) was transplanted in June and harvested in September, 2008. The third DS crop (C6), the last crop of the experiment was transplanted in December and harvested in February, 2008.

Soil and plant analysis

Soil samples were taken from the top 0-20 cm at the beginning of experiment, and from all treatments at the completion of the experiment. The samples were processed and analysed for pH, organic carbon, total N, extractable P and K (Rayment and Higginson 1992). Grain samples were analysed for N, P, K, Na, Fe, Mn, Cu, Zn, and B concentration for assessing grain quality.

Profits of fertilizer use

Returns from applying fertilizers were determined by subtracting the total cost of fertilizer inputs from the income from paddy rice at harvest (Dobermann and Fairhurst 2000). The farm-gate price of paddy used in the calculation ranged from 130-305 USD/tonne. The price of fertilizers used was as follows: cow manure 10 USD/tonne, urea 30-70 USD/100 kg, DAP 36-110 USD/100 kg, and KCl 35-110 USD/100 kg. These ranges of price were based on the local market price from 2005 when the experiment started to 2008 when the experiment ended.

Results

Rice responded strongly to the application of nutrients in crop 1 but the strongest effect was the OI application (Table 1). Under each SNMS, there was no significant difference in yield levels between fertilizer regimes. The actual grain yield ranges were 2.33-2.55, 3.62-3.79, and 4.12-4.23 t/ha under O, I, and OI systems, respectively (Table 1, C1). The addition of organic fertilizer with inorganic ones produced an extra 0.4-0.6 tof grain yield/ha. Response on grain yield to SNMS remained strong for the subsequent crops, and the FR effects became significant under each SNMS. Under the O system, the production yield accumulated after 6 crops were 5.9, 5.0, 8.7, and 11.7 t/ha for FR1, R2, FR3, and FR4 regimes, respectively. Under I system, production yields increased by 49-59% over that of the O system, and the increases responded well to fertilizer regimes with cumulative yields of 9.3, 6.4, 11.1, and 13.4 t/ha for FR1, R2, FR3, and FR4 regimes, respectively. Under the OI system, the cumulative yields after six rice crops were 8.6, 7.3, 14.3, and 16.3 t/ha for FR1, R2, FR3, and FR4 regimes, respectively (Table 1, C6). The dry season crops had very low yield (<1 t/ha) due to a variety of constraints including rats and birds, possibly irrigation water quality and high temperature effects.

Table 1. Effect of nutrient regimes (FR) on cumulative grain yield under three soil nutrient management systems (SNMS). LSD is least significant difference for comparison between treatments in each crop number.

Crop number	SNMS	Cumulative grain yield (t/ha)				LSD (P=0.05)
		FR1	FR2	FR3	FR4	SNMS*FR
C1	O	2.52	2.33	2.40	2.55	0.398
	I	3.78	3.71	3.62	3.79	
	OI	4.12	4.20	4.23	4.19	
C6	O	5.88	5.02	8.65	11.67	1.075
	I	9.29	6.37	11.10	13.44	
	OI	8.57	7.30	14.31	16.30	
Increase	O	3.36	2.69	6.25	9.11	
(C6-C1)	I	5.52	2.66	7.48	9.65	
	OI	4.45	3.10	10.08	12.11	

After 6 crops, soil pH increased by 0.39, 0.64, and 0.67 in O, I, and OI systems, respectively. Soil organic C increased by 0.04-0.09%, exchangeable K increased by 0.03-0.08 cmol/kg, and there was no change in soil N, while extractable P increased by 4.1 mg/kg with the OI system compared with O and I systems (Table 2). At the beginning of the experiment, soil was strongly acidic (pH, 1:5 water ≅ 5) but it was only moderately acidic after 6 crops. The values of organic C, total N, Olsen P, and exch. K measured at the beginning of experiment were rated as very low to low, and while most of them increased after 6 cropping seasons the values remained very low (Hazelton and Murphy 2007; Daly and Wainiqolo 1993). For example, extractable P values increased from 1.3-1.7 in the O and I systems to 5.4 mg/kg in OI system; and exchangeable K increased from <0.1 to >0.1 cmol/kg after 6 crops (Table 2). Grain analysis showed a low level of K, Fe, and Mn concentrations, but a high level of Zn, Na, and Cu concentrations whereas N and P concentrations were generally in an adequate range (data not presented).

Table 2. Effect of cropping on selected soil chemical properties under three soil nutrient management systems (SNMS). [A]Hazelton and Murphy (2007) otherwise expressed. [B]Daly and Wainiqolo (1993).

Time	SNMS	pH (1:5, Soil:H_2O)	Organic C (%)	Total N (%)	Olsen P (mg/kg)	Exch. K (cmol/kg)
Before experiment	O	5.03	0.30	0.03	1.74	0.06
	I	5.08	0.31	0.03	1.47	0.10
	OI	5.00	0.25	0.03	1.34	0.16
After 6 crops	O	5.42	0.34	0.04	1.34	0.14
	I	5.72	0.37	0.03	1.48	0.17
	OI	5.67	0.34	0.03	5.39	0.19
Changes	O	0.39	0.04	0.01	-0.40	0.08
	I	0.64	0.06	0.00	0.00	0.06
	OI	0.67	0.09	0.00	4.05	0.03
Interpretation [A]		Strongly to moderately acidic	Extremely low	Very low	Very low [B]	Low to very low [B]

The actual profit ranges were 253-282, 407-430, and 422-437 USD/ha under O, I, and OI systems, respectively (Table 3, C1). After the first crop, the SNMS and fertilizer regimes had a significant effect on cumulative profits. Under the O system, the means of profit accumulated after 6 crops were 973, 793, 1473, and 1994 USD/ha for FR1, R2, FR3, and FR4 regimes, respectively (Table 3, C6). Similar response patterns occurred in the I and OI systems, but with greater overall profit. In the I system, FR3 and FR4 produced the highest profit values of 1783-1961 USD/ha; and in the OI system, FR3 and FR4 provided profit values of 2296-2327 USD/ha. The very low yield of DS crops strongly influenced the profit of fertilizer use.

Table 3. Effect of fertilizer regimes (FR) on cumulative profits of nutrient use under three soil nutrient management systems (SNMS). LSD is least significant difference for comparison between treatments in each crop number.

Crop number	SNMS	Cumulative profits of fertilizer use (USD/ha)				LSD (P=0.05)
		FR1	FR2	FR3	FR4	SNMS*FR
C1	O	277	253	262	282	51.7
	I	428	419	407	430	
	OI	422	433	437	432	
C6	O	973	793	1473	1994	199.4
	I	1208	973	1783	1961	
	OI	1310	1058	2296	2327	
Increment of profit	O	696	540	1211	1712	
(C6-C1)	I	781	554	1375	1532	
	OI	887	625	1860	1895	

Conclusion

In the combined OI system, the extra rice grain yields of 0.4-0.6 t/ha produced by the effect of organic fertilizer did not significantly change profit in the first crop, but it effects on grain yield and profit became very clear after several crops when nutrients were added to either every WS or both WS and DS crops. The combined OI system appears to be a more productive and sustainable soil nutrient management approach than others as measured by crop yields, profits, and soil fertility parameters. There was no significant effect of SNMS on grain concentration of the essential elements or sensory factors that might affect the quality of rice grain. A thorough assessment of the OI system requires further work on assessing nutrient use efficiency under both rainfed and fully irrigated production systems.

References

Bell RW, Seng V (2004) Rainfed rice-growing soils of Cambodia, Laos, and Northeast Thailand. In 'Water in Agriculture'. (Eds V Seng, E Craswell, S Fukai, K Fischer) pp.161-173. (ACIAR Proceedings No. 116: Canberra ACT).

Daly BK, Wainiqolo JL (1993) Guide to interpretation of agricultural sample analysis results. In 'Fiji Agricultural Chemistry Laboratory Technical Report 04/93'. (Fiji Agricultural Chemistry Laboratory. MAFF: Fiji).

Dobermann A, Fairhurst T (2000) Economics of fertilizer use. In 'Rice: Nutrient disorders & nutrient management'. pp. 38-39. (Potash & Phosphate Institute, Potash & Phosphate Institute of Canada, and International Rice Research Institute).

EIC (2006) 'Cambodia Agriculture Development Report' (June 2006). (Economic Institute of Cambodia, Phnom Penh: Cambodia).

Hazelton P, Murphy B (2007) 'Interpreting soil test results'. NSW Department of Natural Resources. (CSIRO Publishing: Victory).

IRRI (2007) 'CropStat for Windows 7.2'.(International Rice Research Institute. Manila: Philippines).

NIS (2008) Agriculture, forestry and fisheries. In 'Statistical Yearbook of Cambodia 2008'. pp. 209-230. (National Institute of Statistics Publication. Phnom Penh: Cambodia).

Rayment GE, Higginson FR (1992) 'Australian Laboratory Handbook of Soil and Water Chemical Methods'. (Inkata Press: Melbourne).

Seng V, Bell RW, White PF, Schoknecht N, Hin S, Vance W (2005) Sandy soils of Cambodia. In 'Proceedings of the First Symposium on the Management of Tropical Sandy Soils'. (The Land Management Office, FAO Regional Office for Asia and the Pacific). pp. 42-48. (Bangkok: Thailand).

Seng V, Bell RW, Willett IR (2004) Amelioration of growth reduction of lowland rice caused by a temporary loss of soil water saturation. *Plant and Soil* **265**, 1-16.

Seng V, Ros C, Bell RW, White PF, Hin S (2001) Nutrient requirement of rainfed lowland rice in Cambodia. In 'Increased Lowland Rice Production in the Mekong Region)'. (Eds S Fukai, J Basnayake) pp. 170-178. (ACIAR Proceedings No. 101: Canberra ACT).

White PF, Oberthur T, Sovuthy P (1997) 'The soils used for rice production in Cambodia: a manual for their identification and management'. (Cambodia IRRI Australia Project. Phnom Penh: Cambodia).