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YIELD TRENDS AND APPARENT NUTRIENT BALANCES IN INTENSIFIED AND DIVERSIFIED RICE-BASED CROPPING SYSTEMS

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SUMMARY

A long-term field trial was conducted to determine yield trends in relation to nutrient uptake and efficiency in different rice-based cropping systems. The cropping systems had a significant effect on wet season rice yield when residues were not recycled but had no effect otherwise. Rice yield decreased after the first year of crop residue incorporation but increased every year thereafter. Rice yield was significantly affected by residual nutrients applied to dry season crops. The highest residual effect was observed in tomato and sweet pepper to which the highest nitrogen (N), phosphorus (P) and potassium (K) rates were applied. Maize, sweet pepper, and tomato responded well to NPK application, garlic had a low response and mungbean had no response. A relay crop served as a catch crop for excess nutrients and as shade to minimize sunscald effects for tomato and sweet pepper fruits.

INTRODUCTION

The farming systems in the rainfed lowlands of the Ilocos Region in the Philippines are highly diversified. Weather conditions are erratic and unpredictable during the rainy season from June to November, and relatively dry for the rest of the year. Rice (*Oryza sativa*) is grown during the wet season (WS) depending entirely on rainwater. High-value upland crops are grown during the dry season (DS) with deep wells as the water source (Lucas *et al*., in press). Crops grown after rice include C_3 plants such as legumes and C_4 plants such as maize, so nutrient requirements and utilization efficiencies are highly varied. This study was part of the Rainfed Lowland Rice Research Consortium (RLRRC) project to assess the sustainability of the different crop sequences with special reference to nutrient utilization through a long-term trial comprising major rice-based cropping systems commonly practiced by farmers in Ilocos Norte, Philippines.

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In the past, most studies focused on nitrogen (N) dynamics and balance in lowland rice–legume cropping systems under irrigation (Buresh *et al.*, 1989; George *et al.*, 1993; 1995) and rainfed conditions (Ladha *et al.*, 1996). Recently, Tripathi *et al.* (1997) carried out a comprehensive study of N dynamics and balance in intensive and diversified lowland rice-based cropping systems on an experimental farm and in farmers' fields in Ilocos Norte, Philippines. In lowland rice-based cropping systems, the N dynamics are very different from those in the uplands. During the WS, when the soil is saturated, limited O_2 availability restricts nitrification and NH_4^+-N remains as the major form of N available to the rice crop. The drying of soil that normally occurs at the end of the rice crop favours aerobic N transformation, resulting in nitrification of NH_4^+-N to NO_3^--N. Accumulated NO_3^--N is prone to losses by denitrification and leaching during soil flooding. This is typical of N dynamics in irrigated and rainfed lowlands, but the magnitudes of different processes vary in the two water regimes.

There is no published data on how DS crops affect NPK availability for the next WS rainfed rice crop and *vice versa*. In the Ilocos Region, different DS cash crops are grown using different rates of NPK fertilizers, and relay crops (seeds sown either by dibble or drill method with proper spacing between rows or hills of the main crop during its early reproductive stage) are commonly grown for animal feeds or for additional farm income. These systems need to be studied for a conceptual understanding of their soil fertility management requirements.

This first report on the long-term trial focuses on (1) changes in rice yield over five years as related to different N levels; (2) effect of DS cropping on the WS rice crop; (3) effect of the rice crop on the following DS crops; (4) value of the relay crop as a catch crop for excess nutrients applied to DS crops; and (5) nutrient (NPK) input/output of the different cropping systems in 1995.

MATERIALS AND METHODS

The experimental site

The study was conducted at the RLRRC Batac key site, Mariano Marcos State University (MMSU), Ilocos Norte (lat 18°04′N, long 120°32′E, 17.9 m altitude). Ilocos Norte has a humid tropical climate characterized by distinct hot and dry weather from November to June, and a monsoon season from June to October. The average total annual rainfall during the experimental period (1991–95) was 2024 mm and about 80% of this occurred from July to October. The mean annual maximum and minimum temperatures were 32.7 °C and 22.9 °C respectively.

The experimental site is located on a flat plain of a fluvial sediment (Subagjo and Aragon, 1993). The soil is moderately drained, with a groundwater table at a depth of 9–10 m during the dry months. The soil is classified as a Isohyperthermic Udic Eutropept clay loam and, at a depth of 0–25 cm, it had a pH 8.1 and per kg soil contained 4.3 g carbon (C), 0.54 g N, 8.3 mg Olsen P, 8.1 g exchangeable potassium (K) and 39.8 cmol cation exchange capacity.

Experimental design and treatments

Treatments were laid out in strip split-plot design (Gomez and Gomez, 1984) with four replications and the plot size was 45 m^2. The rates of fertilizer application were N applied during the wet season to rice at 0, 30, 60, 90 or 120 kg N ha^{-1} plus a blanket application of 13 kg P ha^{-1} (increasing to 26 kg P ha^{-1} in the 1995 wet season) and 25 kg K ha^{-1}. The cropping systems (WS–DS–relay crop) were rice–tomato (*Lycopersicon esculentum*)–maize (*Zea mays*), rice–sweet pepper (*Capsicum annuum*)–maize, rice–mungbean (*Vigna radiata*)–maize, rice–garlic (*Allium sativum*)–mungbean and rice–maize–mungbean. DS crops were either unfertilized or given recommended rates of N, P and K per ha in elemental form. These rates for the DS crops were 90-26-50 for garlic, 170-57-163 for sweet pepper and tomato, 30-13-25 for mungbean and 120-26-50 for maize.

In rice and the DS crops, N, P and K were applied as urea, single superphosphate and muriate of potash respectively. Previously, urea N was applied to rice in two equal split applications, as a basal application and at panicle initiation stage. The whole amounts of single superphosphate and muriate of potash were applied as a basal application. Starting in the 1995 WS, N was applied to rice in four equal split applications, a basal application, at mid-tillering, at panicle initiation and at flowering. The whole amount of NPK was applied as a basal application in mungbean. For sweet pepper and tomato, a basal application of 90-39-75 kg NPK ha^{-1} was applied, 40-18-34 kg was applied two weeks after transplanting and 40-0-54 kg one month after transplanting. For maize, all of the P and K were applied as basal applications, and one-third of the N was applied each as a basal application, at 30 d after planting (DAP) or before hilling-up, and at 60 DAP. For garlic, all the P and K and two-thirds of the N were applied during sowing, and rice straw at 10.7 t ha^{-1} was applied as a mulch immediately after sowing. The last third of the N was applied at 60 DAP or during early bulb formation. From 30 to 60% of the mulch used for garlic was taken from outside sources.

Crop management

Land preparation for the rice crop was carried out in July when adequate water was accumulated in the field for puddling. Twenty-five-day-old rice seedlings (cv. BPI Ri 10 with 113 d maturity) were transplanted at 20 cm × 20 cm spacing using two to three seedlings per hill. The rice crop depended entirely on rainfall.

After rice, the soil was allowed to dry and then the land was prepared for the planting of DS crops. A hand tractor was used for the thorough preparation of garlic plots during the 1992–93 DS cropping as well as for the tomato, sweet pepper, maize, garlic and mungbean plots. In the following years, there was no ploughing of the garlic plots. Instead, the plots were sprayed with herbicide prior to garlic planting.

Sweet pepper and tomato were established by transplanting 4- and 3-week-old seedlings at 50 cm × 40 cm and 100 cm × 40 cm spacing respectively. Maize, mungbean and garlic were established directly in the field. Maize seeds were dibbled at a spacing of 20 cm along the furrows which were 75 cm apart.

Mungbean seeds were drilled 50 cm apart along the furrows at 20 kg seed ha^{-1}, and the seedlings were thinned to 20–25 plants per linear m. Garlic was established by dibbling garlic cloves at 20 cm × 20 cm and the plots were mulched with rice straw. All DS crops were irrigated with water drawn from a tube well using a water pump.

Relay cropping started during the 1994 DS. The relay crop was maize (glutinous variety) in the rice–tomato, rice–sweet pepper and rice–mungbean systems and mungbean in the rice–garlic system. In the rice–maize system, mungbean was planted after the maize harvest. Maize was relay planted to sweet pepper and tomato 50 DAP, and to mungbean after hilling up about 30 DAP. Mungbean was relay planted to garlic at 60 DAP. The maize was harvested green.

Crop residue management

Crop residues were removed from the experimental plots in 1991, but all crop residues from the 1992 WS and the 1993 DS crops, including the rice straw mulch added to garlic, were incorporated into the soil at the time of land preparation for the rice crop in the 1993 WS. All crop residues were incorporated using a hand tractor with a spike-tooth harrow. The annual rate of incorporated crop residues averaged 7.3 t ha^{-1}.

Plant sampling and analyses

The rice crop yields were measured from 5 m^2 and the harvest area for the main DS and relay crops ranged from 10 to 20 m^2 depending on the row spacing of the crop. Five plant samples from each replicate plot of the main as well as relay crops, and sample rice plants from five hills were chopped, oven-dried and subsampled for NPK analysis. The dry matter was separated from the seeds or fruits. The dry weights of rice and DS crops, including the residues that were recycled or incorporated back into the soil, were recorded. Rice grain yield was expressed at 14% moisture. Crop residues were incorporated using a hand tractor with a spike-tooth harrow during land preparation for rice transplanting. Total plant N in rice and the DS crops was determined by the semimicro-Kjeldahl method (Bremner and Shaw, 1958). Plant samples were dry ashed and to each sample extract 2N nitric acid was added. Phosphorus was analysed by the vanadate-molybdate-yellow method by spectrophotometer and potassium by the flame photometric method (Chapman and Pratt, 1961).

Statistical analysis

Analyses of variance for strip split-plot design and regression analyses were carried out as described in Gomez and Gomez (1984). Analyses of parallelism were done to compare the regression relationship of annual NPK applied with NPK uptake and NPK input/output in the different cropping systems (SAS Institute, 1985).

RESULTS

Effect of cropping systems and N applied to rice on rice yield

Analyses of variance showed that WS rice yields were significantly affected by N application in all the field trials from 1991 to 1995 (Table 1). Rice grain yield in the 1991 WS crop was only 0.9 t ha^{-1} without fertilizer application (Table 2). In the same year, yield increased when the rate of N increased from 30 to 90 kg ha^{-1}, but declined at 120 kg ha^{-1}. In contrast, yield increased with rates of N from 0 to 120 kg ha^{-1} in 1992 to 1995. Combined analysis had also shown that yield data from 1991 to 1995 varied significantly across years. Such variation in yield was shown by the decline in yield in 1993 and an increase in 1994 and 1995.

Differences in rice yield did not appear to be related to differences in the amount and distribution of rainfall. The total annual rainfall in 1991 was 1895 mm, 1992 2497 mm, 1993 1677 mm, 1994 2508 mm and 1995 1543 mm, and in all years 80% of total annual rainfall occurred from July to October (WS) with interspersed dry spells. The amount and distribution patterns of rainfall were similar during 1993 and 1995.

Cropping system had a significant effect on grain yield in 1992 and 1993 (Table 1). In 1992, the yield was lowest in the rice–sweet pepper system at all rates of N.

Table 1. F-values from analyses of variance for rice grain yield in the 1991–95 wet seasons at Batac, Philippines.

Source of variation	1991	1992	1993	1994	1995
Nitrogen applied to rice (N)	24.1**†	38.1**	46.3**	97.5**	64.5**
Cropping system (C)	—	8.2**	5.5**	< 1.0 ns	1.8 ns
N × C	—	1.7 ns	< 1.0 ns	1.9*	< 1.0 ns
Fertilizer applied to dry season crop (F)	—	3.0 ns	8.5**	81.9**	37.6**
N × F	—	< 1.0 ns	1.3 ns	< 1.0 ns	2.5*
C × F	—	1.8 ns	2.7*	5.1**	5.0**
N × C × F	—	< 1.0 ns	< 1.0 ns	1.5 ns	< 1.0 ns

†** and *, significant at the 1% and 5% levels respectively; ns, not significant at the 5% level.

Table 2. Rice grain yields (t ha^{-1}) as affected by rates of nitrogen (N) fertilizer in 1991–95 at Batac, Philippines.

N applied to rice (kg ha^{-1})	1991	1992	1993	1994	1995
0	0.9	1.3	1.0	2.2	2.6
30	1.3	1.7	1.4	2.6	3.4
60	1.6	2.4	1.9	3.6	3.9
90	2.1	3.0	2.4	4.1	4.2
120	1.5	3.2	2.7	4.6	4.7
s.e.d.†	0.11	0.19	0.15	0.14	0.14

†Standard error of the difference for nitrogen means averaged over five cropping seasons.

Rice–maize, rice–garlic and rice–mungbean had higher rice yields than rice–tomato at 60 and 120 kg N ha^{-1} (Fig. 1). When crop residues were incorporated for the first time in the 1993 WS, rice yields declined compared with 1992 (Table 2). The role of incorporated crop residues in the immobilization of native and applied N was therefore indicated. The average annual amount of crop residues (rice straw, DS and relay crop residues, and weeds) ploughed back was 7.3 t ha^{-1} from 1993 to 1995. Hence, with residue recycling, the variation in rice response among DS crop systems disappeared. Analyses of variance showed that, in 1994 and 1995, the cropping system had no significant effect on rice grain yield (Table 1) despite the inclusion of a third or relay crop (maize or mungbean). However, there was a significant interaction between cropping system and N applied to rice in 1994 when rice yields in different cropping systems varied significantly only at

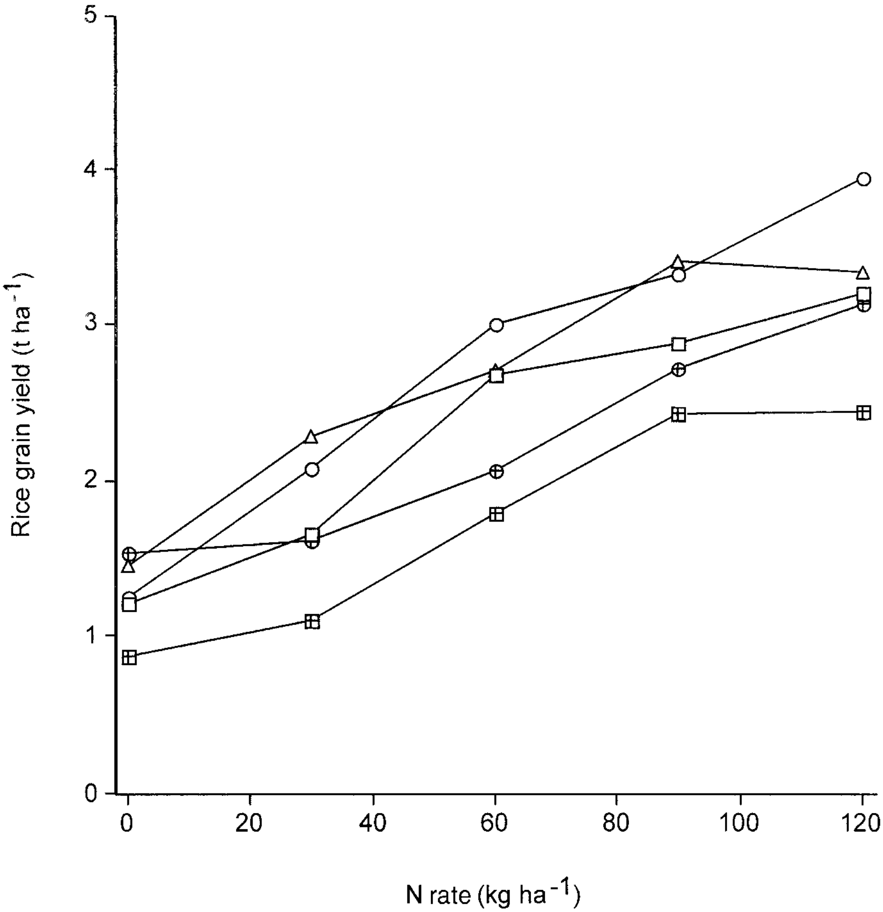

Fig. 1. Rice grain yields in different cropping systems (C) (rice–mungbean, —□—; rice–maize, —○—; rice–garlic, —△—; rice–tomato, —⊕—; rice–sweet pepper, —⊞—) as affected by nitrogen (N) rate in the 1992 wet season at Batac, Philippines. S.e.d. for C means at each N = 0.29; s.e.d. for N means at each C = 0.25.

the 0 kg N ha^{-1} rate (Fig. 2). All cropping systems, however, showed increasing rice yields from 1993 to 1995, with the largest increase in 1994, demonstrating the significant effect of crop residues on succeeding rice crops (Table 3).

Effect of fertilizer application to DS crops on rice yield

Wet season rice yields were significantly affected by fertilizer applied to DS crops from 1993 to 1995. During these years, a significant interaction between cropping system and fertilization was observed (Table 1). Tomato and sweet pepper, given the highest NPK rates, had the highest residual effects in 1994 and 1995, resulting in an average increase in rice yields over the unfertilized control of 0.70 and 0.50 t grain ha^{-1} respectively (Table 3).

There was a significant interaction between fertilizer applied to DS crops and N applied to WS rice only in 1995 (Table 1). In this year, rice grown with 0–60 kg N ha^{-1} after a fertilized DS crop produced higher yields than that after a DS crop which did not receive fertilizer (Table 4). With 90–120 kg N ha^{-1} applied to rice, yields did not vary significantly in fields with and without fertilization during the preceding DS crops.

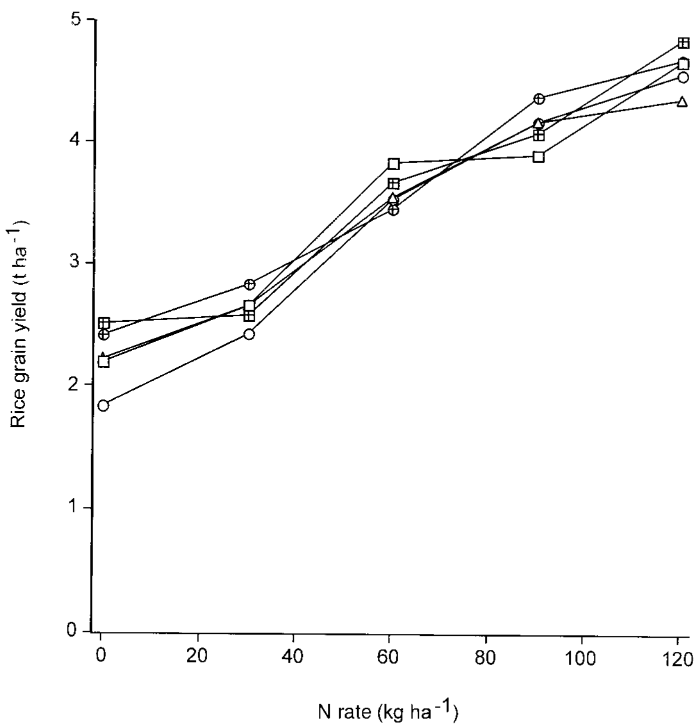

Fig. 2. Rice grain yields in different cropping systems (C) (rice–mungbean–maize, —□—; rice–garlic–mungbean, —△—; rice–maize–mungbean, —○—; rice–tomato–maize, —⊕—; rice–sweet pepper–maize, —⊞—) as affected by nitrogen (N) rate in the 1994 wet season at Batac, Philippines. S.e.d. for C means at each N = 0.24; s.e.d. for N means at each C = 0.20.

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Table 3. Rice grain yields (t ha^{-1}) as affected by cropping systems and fertilizer application to dry season crops in the 1992–95 wet seasons at Batac, Philippines.

Dry season crop (C) and fertilizer (F)	1992	1993	1994	1995
Maize				
Unfertilized control	2.8	1.7	3.2	3.6
Recommended rate	2.7	2.0	3.4	3.8
Garlic				
Unfertilized control	2.6	1.8	3.2	3.7
Recommended rate	2.6	1.8	3.5	3.9
Mungbean				
Unfertilized control	2.4	2.1	3.3	3.7
Recommended rate	2.0	2.0	3.6	3.7
Tomato				
Unfertilized control	2.1	2.0	3.2	3.8
Recommended rate	2.3	2.2	3.9	4.2
Sweet pepper				
Unfertilized control	1.8	1.5	3.2	3.5
Recommended rate	1.6	1.9	3.9	4.1
s.e.d. F means at each C	0.16	0.13	0.10	0.10
s.e.d. C means at each F	0.22	0.14	0.20	0.14

Table 4. Rice grain yields (t ha^{-1}) response to the interaction effects of nitrogen (N) fertilizer applied to rice and the recommended rates of fertilizer applied to the dry season (DS) crops in the 1995 wet season at Batac, Philippines.

Nitrogen fertilizer (N) (kg ha^{-1})	Fertilizer applied to DS crops (F)	
	Recommended rate	Control
0	2.9	2.4
30	3.6	3.2
60	4.1	3.7
90	4.3	4.2
120	4.8	4.6
s.e.d. F means at each N	0.10	
s.e.d. N means at each F	0.16	

Effect of recommended fertilizer on the yield of the main DS crops

All main DS crops, except mungbean, responded to the application of the recommended amount of fertilizer. Mungbean yield was 0.6–0.8 t ha^{-1}, with or without NPK fertilizers. The highest response to the recommended fertilizer rate was obtained in sweet pepper and tomato. Garlic responded to fertilizer application in all years, except in 1994. The response of garlic to NPK was lower than that of sweet pepper, tomato or maize (Table 5).

Table 5. Marketable yield of dry season (DS) crops as affected by fertilizer level at Batac, Philippines in 1992–95.

DS crop	N applied to rice (N) (kg ha^{-1})	NPK applied to DS crop (F) (kg ha^{-1})	1992	1993	1994	1995
Garlic	0	0-0-0	2.2	1.9	2.0	2.1
		90-26-50	2.7	3.1	2.1	2.0
	120	0-0-0	2.1	2.3	2.3	1.9
		90-26-50	2.7	2.9	2.1	2.3
s.e.d. F means at each N			0.2	0.3	0.2	0.2
s.e.d. N means at each F			0.2	0.2	0.2	0.2
Maize	0	0-0-0	5.1	2.0	0.9	1.5
		120-26-50	6.0	7.5	5.0	4.9
	120	0-0-0	4.6	3.2	1.2	1.9
		120-26-50	6.1	9.0	5.4	4.5
s.e.d. F means at each N			0.3	0.5	0.4	0.4
s.e.d. N means at each F			0.4	0.7	0.4	0.4
Mungbean	0	0-0-0	0.8	0.6	0.8	0.8
		30-13-25	0.8	0.6	0.8	0.8
	120	0-0-0	0.8	0.5	0.7	0.7
		30-13-25	0.8	0.6	0.8	0.8
s.e.d. F means at each N			0.2	0.1	0.2	0.1
s.e.d. N means at each F			0.2	0.1	0.2	0.1
Tomato	0	0-0-0	17.9	15.5	4.3	18.9
		170-57-163	37.5	31.2	13.2	50.8
	120	0-0-0	16.1	35.5	5.2	16.3
		170-57-163	42.0	47.4	14.6	50.5
s.e.d. F means at each N			4.0	9.1	2.3	3.8
s.e.d. N means at each F			4.4	7.8	2.0	3.9
Sweet pepper	0	0-0-0	1.5	2.9	1.1	1.4
		170-57-163	5.0	20.1	10.7	9.9
	120	0-0-0	1.3	3.5	2.1	1.9
		170-57-163	4.0	22.1	11.6	9.9
s.e.d. F means at each N			0.8	1.5	1.4	1.2
s.e.d. N means at each F			0.7	1.4	1.2	1.3

Nitrogen applied to the rice crop had little effect on the yield of the succeeding DS crops. The only exception was rice–tomato in 1993, where the N applied to the preceding WS rice crop had a significant residual effect (Table 5).

Effect of cropping systems and fertilizer level on the yield of relay crops

The yield of relay crops was significantly affected by fertilizer application to the DS crops (Table 6). Green maize was harvested when the recommended rates of NPK were applied to sweet pepper and tomato, but no green maize was produced from unfertilized sweet pepper and tomato. During the 1995 DS cropping, relay maize planted in the tomato plots at 50 DAP was shaded by the tomato plants,

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Table 6. Relay crop yields (t ha^{-1}) as affected by cropping system and rate of fertilizer application (F) for the main dry season (DS) crop in the 1994 and 1995 dry seasons at Batac, Philippines.

	1994		1995	
	Fertilizer (F)‡		Fertilizer (F)‡	
Cropping system (C)†	Recommended	Control	Recommended	Control
Rice–mungbean–maize	0.00	0.00	0.89	0.80
Rice–tomato–maize	2.15	0.00	0.54	0.00
Rice–sweet pepper–maize	2.38	0.00	5.31	0.00
s.e.d. C means at each F	0.15		0.17	
s.e.d. F means at each C	0.12		0.13	
Rice–garlic–mungbean	0.09	0.17	0.05	0.03
Rice–maize–mungbean	0.30	0.45	0.35	0.51
s.e.d. C means at each F	0.09		0.04	
s.e.d. F means at each C	0.06		0.02	

†Wet season–dry season–relay crop, ‡fertilizer application to DS crops.

and so negligible green maize yield was produced in the fertilized plots. In rice–mungbean–maize, no green maize was produced in 1994, either with or without the recommended fertilizer rate for the DS crop. However, in 1995, 0.8–0.9 t green maize ha^{-1} was obtained with mungbean as the main DS crop, with or without fertilizer.

The yield of relayed mungbean was relatively higher in the rice–maize–mungbean than in the rice–garlic–mungbean system. Moreover, fertilizer applied for the main DS crop had no positive effect on the relayed mungbean yield.

Nutrient uptake of main DS crop and relay crop

The NPK uptake of maize, tomato and sweet pepper increased with the application of fertilizers, while that of garlic and mungbean did not (Table 7). Nevertheless, marketable garlic yield was higher with fertilizer than without, except in 1994 and 1995 (Table 5).

The amount of NPK absorbed by the relay crop depended largely on the amount of NPK applied to the main DS crop. Fertilizer applied to the main DS crop had no significant positive effect on the NPK uptake of relayed mungbean in the rice–garlic and rice–maize systems or relayed maize in the rice–mungbean system. On the other hand, the high fertilizer rates applied to sweet pepper and tomato had significant positive effects on the NPK uptake of relayed maize. In 1994 and 1995 maize relayed to sweet pepper absorbed an average of 28-9-41 kg NPK ha^{-1} from the fertilizer applied during the main DS crop. This showed that a relay crop could serve as a 'catch' crop for excess plant nutrients (Table 7).

Table 7. Average of nitrogen (N), phosphorus (P) and potassium (K) uptake (kg ha^{-1}) by the main dry season (DS) and relay crops in 1994–95 at Batac, Philippines.

			Main DS crop						Relay crop					
			N		P		K		N		P		K	
Main DS crop (C)	Relay crop	NPK applied to DS crop (F) (kg ha^{-1})	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995	1994	1995
Garlic	Mungbean	0-0-0	19.5	15.9	3.7	2.7	21.3	18.6	6.2	1.8	1.2	0.3	7.4	2.8
		90-26-50	20.4	20.2	3.7	3.2	21.7	21.7	4.4	2.4	0.8	0.5	6.7	3.4
Maize	Mungbean	0-0-0	18.8	19.2	6.6	7.0	42.5	68.7	19.7	30.0	3.4	5.6	27.8	50.8
		120-26-50	72.0	64.6	29.7	21.2	143.3	144.1	14.9	20.9	2.3	3.3	20.4	32.6
Mungbean	Maize	0-0-0	37.5	30.6	4.6	4.0	37.4	27.9	1.2	6.3	1.1	3.8	1.8	16.1
		30-13-25	38.5	33.2	5.2	4.4	39.3	31.6	1.2	8.2	0.8	4.5	1.3	17.3
Tomato	Maize	0-0-0	14.4	18.5	1.7	4.9	15.6	69.0	3.1	1.7	1.1	1.0	4.6	4.3
		170-57-163	32.3	62.9	3.7	12.0	38.9	166.6	16.9	6.0	4.8	3.4	20.3	13.5
Sweet pepper	Maize	0-0-0	6.1	3.5	1.2	1.0	11.9	32.8	1.4	0.4	0.9	0.4	3.5	2.0
		170-57-163	51.9	30.3	6.9	5.4	78.5	76.3	29.7	26.8	5.9	11.2	29.2	52.2
s.e.d.														
F means at each C			3.1	3.5	0.6	0.8	4.5	6.7	2.2	0.9	0.3	0.4	2.0	2.8
C means at each F			5.2	7.1	0.8	1.4	9.7	1.4	3.0	1.2	0.5	0.7	3.7	4.3

Nutrient input/output in different cropping systems

The annual NPK uptake increased with increasing rates of NPK fertilizer in all cropping systems, except for P uptake in the rice–garlic–mungbean system and K uptake in the rice–mungbean–maize system where there were no significant correlations between PK uptake and PK applied (Fig. 3, 4 and 5). At the same rate of applied P and K, higher P and K uptakes were observed with higher rates of N application. Analyses of parallelism (SAS Institute, 1985) of regression lines showed that the response to N and P treatments in terms of N and P uptakes varied with cropping system (Fig. 3b and 4b). The annual K uptake was also significantly affected by K application and cropping system but no significant interaction was observed between cropping system and K application in terms of K uptake (Fig. 5c). Among the different cropping systems, rice–garlic–mungbean was the least and rice–sweet pepper–maize and rice–tomato–maize were the most responsive to N application in terms of both yield and N uptake (Fig. 3b). In terms of P uptake, rice–tomato–maize appeared to be the least and rice–maize–mungbean the most responsive to P application (Fig. 4b). Without fertilizer application, NPK uptake among the five cropping systems averaged 55-14-117 kg ha^{-1}, which may be considered as the annual NPK supplying capacity of the soil.

Nitrogen recovery in the harvested products increased with increasing rates of N (Fig. 3a). Rice–tomato–maize had the largest increase at 0.25 kg N kg^{-1} N applied (slope), and rice–garlic–mungbean had the lowest at 0.11 kg N kg^{-1} N applied. Thus, for the rice–tomato–maize system, the increase in N in the harvested products with 60–290 kg N ha^{-1} compared with the control given no N was 15–73 kg; in the rice–garlic–mungbean system, the increase was 7–23 kg N with the application of 60–210 kg N ha^{-1}. In the rice–sweet pepper–maize system, the amount of N in the harvested products increased by 13–64 kg compared with the control with the application of 60–290 kg N ha^{-1}.

The increase in P in the harvested products ranged from 0.14 kg kg^{-1} P applied in rice–tomato–maize to 0.43 kg kg^{-1} P applied in rice–maize–mungbean. The K in the harvested products and applied K correlated in all cropping systems except rice–mungbean–maize with an increase in recovered K of 0.17–0.60 kg kg^{-1} applied K (Fig. 5a).

The NPK net inputs (NPK applied − NPK in the harvested products) increased with increasing rates of NPK fertilizers (Fig. 3c, 4c, and 5c). The highest N (208 kg) and K (109 kg) inputs were observed in rice–sweet pepper–maize at maximum rates of applied N and K. Lower N and K inputs were observed in rice–tomato–maize which received the same NPK rates. Phosphorus inputs in rice–sweet pepper–maize and rice–tomato–maize were similar at the maximum annual rate of 70 P kg ha^{-1}. These results show that a large amount of the N applied was not utilized by the crops and may have been lost by leaching and/or denitrification. The K input was low relative to the K recovered in the harvested products, with the exception of the rice–sweet pepper–maize system, where a large amount of the 163 kg K ha^{-1} K applied as fertilizer was not utilized.

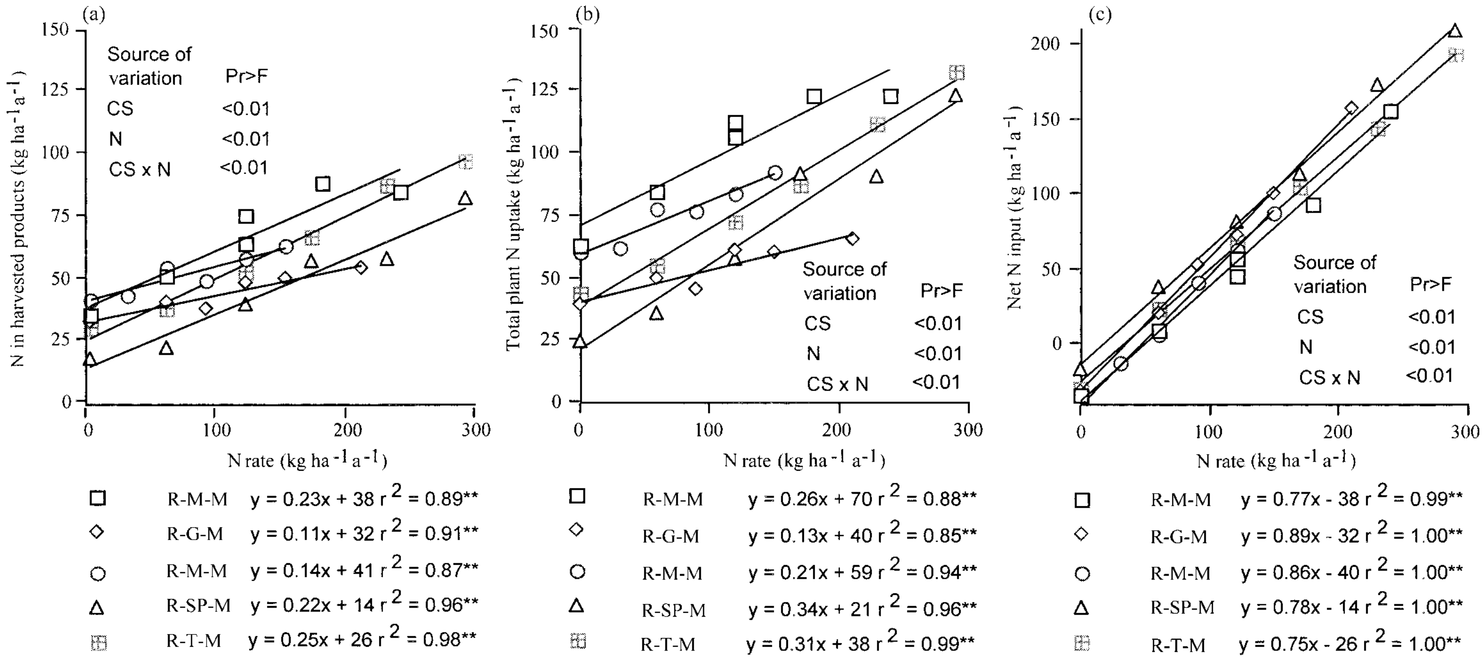

Fig. 3. Regression relationships between the rate of applied nitrogen (N) and (a) N recovered in harvested products, (b) total plant N uptake and (c) net N input/output in five cropping systems: rice–maize–mungbean (R–M–M), rice–garlic–mungbean (R–G–M), rice–mungbean–maize (R–M–M), rice–sweet pepper–maize (R–SP–M), and rice–tomato–maize (R–T–M) in the 1994 wet season to the 1995 dry season at Batac, Philippines.

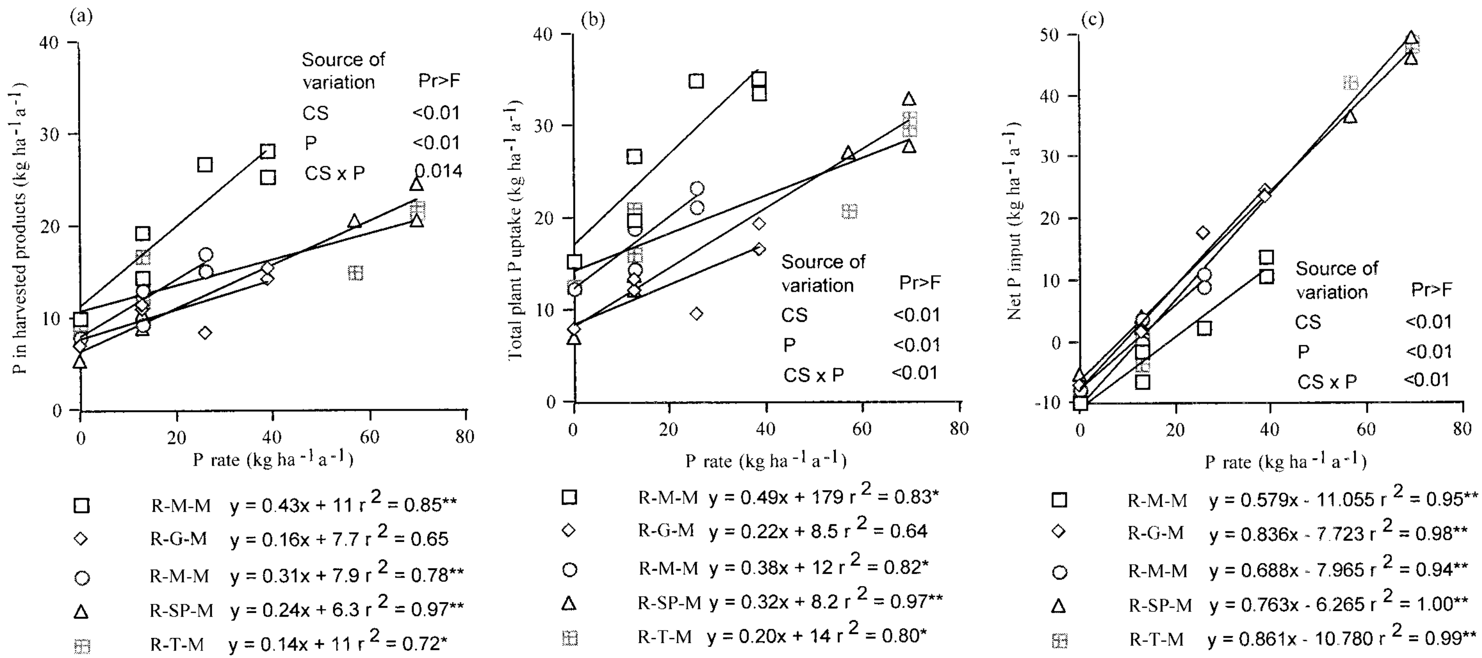

Fig. 4. Regression relationships between the rate of applied phosphorus (P) and (a) P recovered in harvested products, (b) total plant P uptake and (c) net P input/output in five cropping systems: rice–maize–mungbean (R–M–M), rice–garlic–mungbean (R–G–M), rice–mungbean–maize (R–M–M), rice–sweet pepper–maize (R–SP–M), and rice–tomato–maize (R–T–M) in the 1994 wet season to the 1995 dry season at Batac, Philippines.

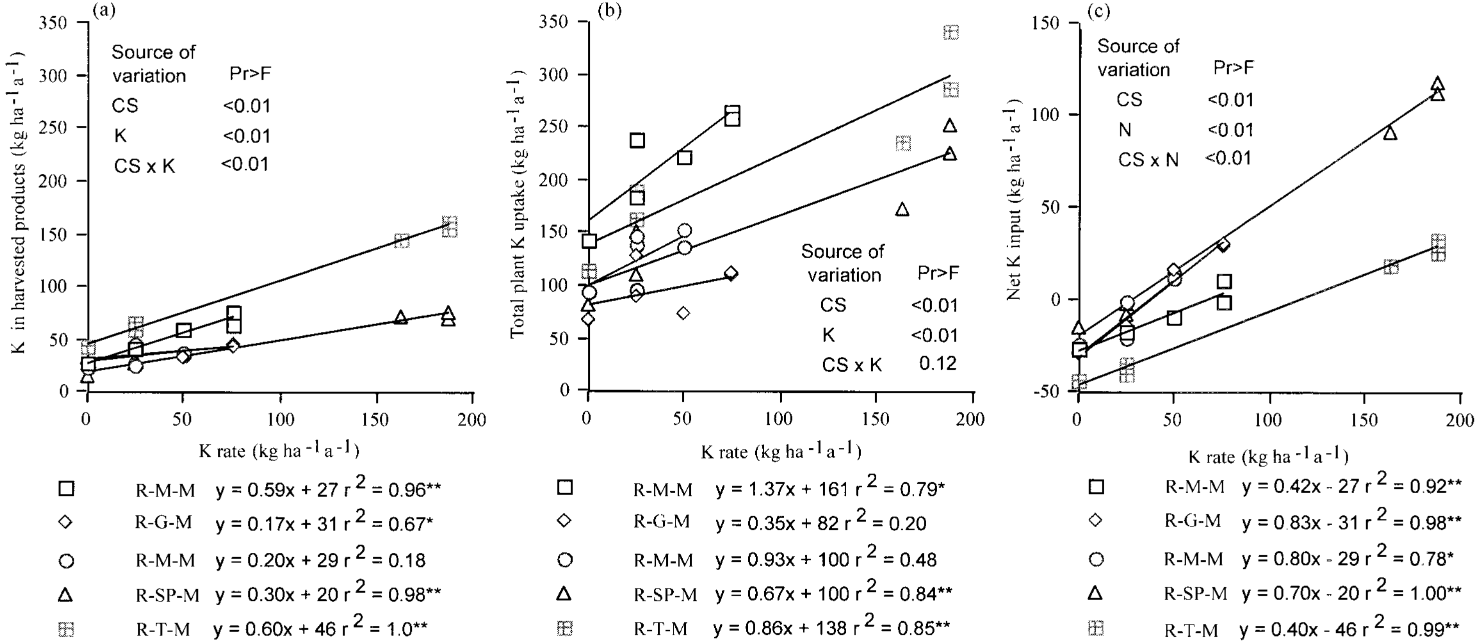

Fig. 5. Regression relationships between the rate of applied potassium (K) and (a) K recovered in harvested products, (b) total plant K uptake and (c) net K input/output in five cropping systems: rice–maize–mungbean (R–M–M), rice–garlic–mungbean (R–G–M), rice–mungbean–maize (R–M–M), rice–sweet pepper–maize (R–SP–M), and rice–tomato–maize (R–T–M) in the 1994 wet season to the 1995 dry season at Batac, Philippines.

DISCUSSION

Without fertilizer application, the rice yield in earlier years was low at 0.9 t ha^{-1}. This was expected because of low soil fertility, particularly total N (0.5 g kg^{-1} soil) and Olsen P (3.8 mg kg^{-1} soil). Yield increased with successive croppings. In 1995, rice yield in the control plot (no NPK) was 2.6 t ha^{-1}. The gradual increase in rice grain yield over the four years could be attributed to (1) the incorporation of crop residues during land preparation for rice, (2) the possible improvement of crop management, and (3) the accumulated residual fertilizer from the DS crops in the fertilized plots. Nitrogen is subject to losses, but there should be a gradual build-up of P and K in the soil.

The main constraints in rainfed lowland rice cultivation are the fluctuating soil moisture conditions and the periodic soil cracking and flash flooding, causing large N losses to occur. The NPK uptake indicated that a large amount of the applied N was not utilized by the different crops. There was little residual effect on the DS crops from N applied to rice. The effect of N applied to DS crops on rice in the WS was more pronounced but still low, with a residual value of 0.5 t ha^{-1} grain yield. Thus, large losses also occurred because the transition period from the harvested DS crops to the succeeding rice crop was about 3–4 months. In an earlier study in the same field, large NO_3^--N build-up (ranging from 61 to 239 kg ha^{-1}) in the soil profile was reported, which was apparently lost from the system through leaching and/or denitrification (Tripathi *et al*., 1997). Tripathi *et al.* (1997) estimated total apparent N losses ranging from 34 to 549 kg N ha^{-1} in farmers' fields in Ilocos Norte, with the largest losses observed in rice–sweet pepper.

With rice yields of 2.5–4.0 t ha^{-1}, a 0.3–0.8 t ha^{-1} residual effect (12–20%) is agronomically significant. From a farmers' survey, it was found that tomato and sweet pepper farmers tended to apply less N to rice (an average 72 and 51 kg ha^{-1} in tomato and sweet pepper fields respectively) than farmers growing other DS crops (average 120 kg ha^{-1}) (Lucas *et al*., in press).

Dry season crops have different management and NPK requirements, and therefore received different rates of applied NPK. High rates of NPK (170-57-163 kg ha^{-1}) were used for sweet pepper and tomato, and these crops had the highest NPK net inputs and highest N losses among the cropping systems. As an N-fixing crop, mungbean received the lowest N (30 kg ha^{-1}), did not respond to fertilizer application, and had the lowest NPK net inputs. The poor response of garlic to fertilizer application may be related to the use of a large amount of crop residues both as mulch and incorporated. Actually, the garlic plant has no residual biomass but the straw mulch served as the 'crop residues', since the harvested garlic was tied up in the stem when stored or sold. Ogawa and Dei (1965) reported that crop residues containing 0.5–0.6% N, such as rice straw, immobilize N in the soil. Topdressed N applied to the mulch may have caused high losses and immobilization. After one crop, however, immobilized N is likely to be mineralized. Thus, the mulch which was ploughed under after the garlic crop was expected to improve soil fertility, especially exchangeable K in the long run, which is important to bulb formation. This would reduce responses to NPK fertilizer in the later years.

Mungbean yields of 0.5–0.8 t ha^{-1} are within the range of grain yields obtained in 1965–86 in Asian countries such as India (0.31 t ha^{-1}) and Thailand (0.77 t ha^{-1}) (Chandra Babu and Hallam, 1988). These yield ranges may be considered low. Biological N fixation may have played a major role in mungbean production in the unfertilized control plots, thus producing a yield of 30 kg ha^{-1} equal to that of the inorganic N treatment. A comparison of the N uptake of unfertilized mungbean and maize, as main DS or relay crops, showed that 11–24 kg N ha^{-1} (Table 7) was derived from biological N fixation in mungbean. Mungbean yield and NPK uptake were lower in the garlic–mungbean than the maize–mungbean systems, because the mungbean was actually planted after the maize harvest and produced higher yield due to the early rainfall in May which favoured growth and flowering. However, mungbean relayed to garlic usually required less labour input since the residual soil moisture is maximised and the seeds were just dibbled as practiced by most farmers in the Ilocos Region.

Relay cropping to obtain additional income or animal feed without additional costs is a common practice in the Ilocos Region. This study showed that a relay crop of maize, planted 50 d after planting sweet pepper, could absorb up to 17-15-25% of the NPK applied to the main crop of sweet pepper in 1994 and 1995 (Table 7). The relay crop served as a catch crop, especially to trap soil NO_3^--N which is prone to loss (George *et al.*, 1995; Tripathi *et al.*, 1997). Initial results showed that the residual fertilizer from DS crops only benefitted the succeeding rice crops when catch crops were grown and the residues recycled. Rice yield trends from 1994 to 1995 seemed to show that recycling crop residues in the upland crop–rainfed rice system may eventually reduce the fertilizer requirements for rice. There is, however, a need to improve relay cropping management strategies. Between maize and mungbean, maize appears to absorb larger amounts of nutrients from the soil, but mungbean has biological N-fixing ability.

Timing of sowing the relay crop is crucial because it may compete with the main crop for radiation and nutrients, but it should also be planted early enough to produce grain and make use of the irrigation water applied to the DS crops. Without NPK fertilizer, relayed maize did not produce any green maize in the different cropping systems because of the low availability of native N and P in the soil. Even with NPK fertilizer in the main DS crop, green maize yield was low. In 1994, no green maize was produced when relayed to mungbean because it was planted late. It should have been planted after hilling-up which is usually followed by furrow irrigation which favours better crop establishment as shown by the 1995 cropping. As a rule, the main DS and relay crops should have mutual benefits. Furthermore, maize relayed to mungbean produced the lowest green maize due to lower fertilizer residues compared with tomato and sweet pepper which received the highest NPK input. Maize relayed to sweet pepper was advantageous because it partly shaded the sweet pepper fruits, thereby minimizing sunscalding and resulting in the production of better quality marketable fruits. The green maize yield was higher in 1995 when the maize was planted along the furrows spaced at 50 cm, instead of at the ridge of the sweet pepper as was done during the 1994 cropping. It implies a better utilization of residual fertilizer and irrigation water applied to sweet pepper. Sowing maize in tomato plots earlier than 50 d after tomato planting produced higher green maize yield and the maize plants shaded the tomato fruits to minimize sunscald. Such a strategy could reduce the labour input used by farmers to spread rice straw over the tomato plants in order to ensure better fruit quality, especially the deep red colour required for processing as tomato paste.

It should be noted that solar radiation in the Ilocos region is very intense particularly during the harvesting period and that harvesting is usually done only once. The deep red colour of the tomato fruit is very necessary to their quality, hence there is the need to apply high rates of K. This was reflected by the highest K uptake of 167 kg ha^{-1} for tomato in 1995, compared with the other main DS crops. In 1994, the K uptake of tomato was lower than in 1995 due to uncontrollable field pest problems which resulted in lower yield and consequently K uptake. Maize relayed to tomato produced a higher green maize yield in 1994 than in 1995 due to the shading effect of the tomato plant on the growing maize. In 1995, tomato produced the highest yield of all cropping years, hence more vegetative parts that caused shading for maize planted in between a 1-m row distance of tomato.

The first five years of this long-term trial show increasing rice yields with the number of croppings, and further increases with crop residue incorporation. Fertilizer application to the WS rice did not affect the succeeding DS crops, but DS crop fertilization produced an average yield increase of 0.5 t ha^{-1} in the following WS rice crop. Of immediate concern are the large losses of applied N and non-utilized P and K. Continuous monitoring of crop responses and soil fertility changes is essential for the establishment of crop management strategies for sustained productivity in the intensified and diversified rainfed rice-based cropping systems of the Ilocos Region.

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