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ROLE OF INDIGO IN IMPROVING THE PRODUCTIVITY OF RAINFED LOWLAND RICE-BASED CROPPING SYSTEMS

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SUMMARY

A long-term field experiment was conducted to determine the effects of indigo (*Indigofera tinctoria*) on the productivity of rainfed lowland rice-based cropping systems: rice–tomato, rice–tobacco or soyabean, rice–maize, and rice–garlic. Indigo was grown as an intercrop during the dry season and incorporated as green manure for wet season rice. Dry season crop yields were generally not affected by the indigo intercrop but indigo green manure had a positive effect on rice yields. At the same level of nitrogen (N) inputs, indigo-N produced higher yields than urea-N which may be due to high inorganic N losses.

INTRODUCTION

As in many parts of Asia, the lowland ricefields in Ilocos Norte are used intensively to grow rice (*Oryza sativa*) during the wet season and non-staple food or cash crops during the dry season. Farmers in the province practice various crop sequences such as rice–garlic (*Allium sativum*), rice–tobacco (*Nicotiana tabacum*), rice–mungbean (*Vigna radiata*), rice–tomato (*Lycopersicon esculentum*) and rice–sweet pepper (*Capsicum annuum*). The latter is the most dominant. A socio-economic survey showed that farmers using these crop sequences apply high doses of nitrogen (N) fertilizer ranging from 200 to 600 kg N ha^{-1} for rice and non-rice crops (RLRRC, 1993). Whilst such systems provide attractive economic returns to the farmers, it is not known if the systems of production are sustainable. High cropping intensity with high inputs is likely to affect crop production economics, sustenance of soil fertility and environmental quality. For example, some farmers in Ilocos Norte have indicated that they need to apply higher amounts of inorganic fertilizer to produce the same yield as in previous years. Enormous losses of N from rice–tomato and rice–sweet pepper have been recorded (Tripathi *et al*., 1997) and NO_3-N exceeding 10 mg NO_3-N L^{-1} was found in ground water particularly in

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locations where these cropping sequences are practiced (Gumtang *et al.*, 1999; Shrestha, 1997).

A major concern, therefore, is how to make these highly intensive rice-based production systems sustainable. There is a need to generate and develop appropriate nutrient management strategies to improve and maintain soil fertility, based on the socio-economic conditions of Ilocos Norte. Manures and composts have been used as a means of increasing soil fertility and crop production throughout the history of farming (Avnimelech, 1986). Empirical evidence and theoretical considerations suggest that green manure can contribute to the sustainability of tropical agricultural systems in which rice is a major crop (Ladha and Garrity, 1994). Aside from biological nitrogen fixation, green manure grown after the dry season (DS) crops as a relay crop can capture the excess NO_3-N in the soil before it is leached to deeper soil layers, or lost on flooding rice lowlands (George *et al.*, 1994; Ladha *et al.*, 1996; Shrestha, 1997). Among the green manure species, indigo (*Indigofera tinctoria*) is unique in that it is used by farmers on a considerable scale. Locally known in Ilocano as 'tayum', indigo is grown as a post-rice green manure in the entire Ilocos Region (Garrity *et al.*, 1994). It is generally sown in November to December, mostly as a DS intercrop rather than as a monocrop. It continues to grow and occupy the field after the DS crops are harvested and is then ploughed under as green manure for the wet season (WS) rice crop. Indigo was quite popular as a green manure in Ilocos Norte before the green revolution. However, in recent years the use of indigo has declined in favour of inorganic fertilizer N. This may be because knowledge of the technology resides primarily with the farmers rather than with the research and extension personnel (Garrity *et al.*, 1994). Furthermore, quantitative data on the benefits of indigo to rice as compared with inorganic fertilizer N are scarce. This paper reports the initial findings from a long-term field experiment focusing on the contribution of indigo to the economy of rainfed lowland rice-based cropping systems.

MATERIALS AND METHODS

The field experiment was conducted at the Mariano Marcos State University (MMSU), Batac, Ilocos Norte, Philippines (lat 18°33′N, long 120°33′E), with climate characterized as dry from November to April and wet from May to October. The experimental site is a fluviatile plain with soil classified as an Isohyperthermic Ustic Eutropept clay loam, having a pH 7.7–7.9, organic carbon (C) 0.26–0.47%, total N 0.047–0.060%, Olsen phosphorus (P) < 3 mg kg^{-1} and exchangeable potassium (K) 0.3–0.8 cmol kg^{-1} soil at a depth of 0–25 cm. Soil pH was determined potentiometrically on a 1:1 soil:water ratio and organic C by modified Walkley and Black. Available P was extracted with Olsen solution and exchangeable K by 1N ammonium acetate. Soil P and K extracts were determined colorimetrically using a spectrophotometer and flame photometer, respectively. The analytical procedures followed the standard methods of plant, soil and water analysis (PCARR, 1978).

A long-term experiment was set-up starting in the 1994 dry season. The experiment involved the four most dominant rice–DS crop sequences in the Ilocos Region: rice–tomato, rice–tobacco (replaced by rice–soyabean (*Glycine max*) in 1995), rice–maize (*Zea mays*) and rice–garlic. Rice was grown from July to October while the DS crops were grown from November to April. The experiment followed a strip split-plot design with three replications. The treatments and factorial combinations are given in Table 1.

The size of each sub-plot was 70 m^2. The indigo treatment was implemented as an intercrop of the DS crop component of each cropping sequence and incorporated as green manure for the WS rice crop. Indigo seeds were sown along the rows of the DS crops one month after planting and the sowing time coincided with the irrigation schedule of the DS crops. Dry season crops without an indigo intercrop were included to serve as controls.

All DS crops, with and without the indigo intercrop, were fertilized with the recommended rates (kg NPK ha^{-1}) specific for each crop: garlic, 90-26-50; maize, 120-26-50; soyabean, 60-13-25; tomato, 180-26-117. The fertilizer was applied in

Table 1. Factorial combinations in the long-term field experiment following a strip split-plot design at Batac, Philippines.

Cropping sequence (Horizontal factor)	Wet season inorganic nitrogen treatment (Vertical factor)	Dry season indigo intercrop/wet season indigo green manure (subplot)
Rice–tomato	0N	without indigo
		with indigo
	60N	without indigo
		with indigo
	120N	without indigo
		with indigo
Rice–tobacco or soyabean	0N	without indigo
		with indigo
	60N	without indigo
		with indigo
	120N	without indigo
		with indigo
Rice–maize	0N	without indigo
		with indigo
	60N	without indigo
		with indigo
	120N	without indigo
		with indigo
Rice–garlic	0N	without indigo
		with indigo
	60N	without indigo
		with indigo
	120N	without indigo
		with indigo

two dressings, at planting and one month after planting. DS crops were harvested in February–March while the indigo intercrop was allowed to grow and occupy the field until July or August. The incorporation of indigo as green manure coincided with land preparation for the succeeding rice crop. With or without indigo green manure, the rice crop was given urea at 0, 60 or 120 kg N ha^{-1} applied in two dressings, at transplanting and at the panicle initiation stage. Before transplanting the rice all treatment plots were also given 15 kg P and 25 kg K ha^{-1}.

The fresh weights of tomato fruits and the cured weight of garlic bulbs were measured. The grain yields of soyabean, maize and rice were expressed at 14% moisture, and the yield of rice straw was recorded after drying for 24 h at 70°C; agronomic N use efficiency (ANUE, kg grain kg^{-1} applied N) was computed by subtracting the grain yield of the control plots (0N) from the treated plots and dividing by the total N applied (urea-N plus indigo-N).

Analysis of variance for strip split-plot design was used to analyse the effects of crop sequence (horizontal strip), inorganic N level (vertical strip), and indigo green manure (subplot) on rice grain yields. Variability in ANUE was analysed using ANOVA for strip plot design with crop sequence as the horizontal factor and the combined effect of indigo green manure and inorganic N level (indigo alone, indigo + 60N, indigo + 120N, 60N, or 120N) as the vertical factor. The effects of inorganic N level (main plot) and indigo green manure (subplot) on the yield of each DS crop were determined using ANOVA for split-plot design. Variabilities in biomass, % N and the N accumulation from intercropped indigo were determined using ANOVA for strip plot design with the companion DS crop as the horizontal factor and inorganic N level applied to the preceding rice crop as the vertical factor. All statistical procedures used are described in Gomez and Gomez (1984).

RESULTS

Biomass and nitrogen accumulation of intercropped indigo

Analyses of variance for strip plot design showed that in 1994 and 1995 plant N concentration, biomass and the N accumulation from intercropped indigo were not significantly affected by the companion DS crop (horizontal strip) or inorganic N level (vertical strip) applied to the preceding rice crop. There was no interaction between the companion DS crop and the WS inorganic N level in terms of these parameters in either year. Plant N concentration, biomass and N accumulation averaged 2.06%, 2.94 t ha^{-1} and 57.58 kg ha^{-1} respectively in the 1994 DS, and 2.42%, 2.32 t ha^{-1} and 56.65 kg ha^{-1} in the 1995 DS.

Dry season crop yields as affected by intercropped indigo and inorganic nitrogen levels applied to wet season rice

In 1995 and 1996, inorganic N levels applied to the preceding WS rice did not affect the yields of any of the DS crops. The indigo intercrop had a significant

Table 2. Dry season crop yields (t ha^{-1}) as affected by the rate of inorganic nitrogen (urea-N, kg ha^{-1}) applied to the preceding rice crop and indigo intercropping, in the 1995 and 1996 dry seasons at Batac, Philippines.

	Tomato		Soyabean		Maize		Garlic	
Treatments	1995	1996	1995	1996	1995	1996	1995	1996
Urea-N								
0	35.49	39.43	1.04	2.29	8.71	8.59	1.46	2.85
60	37.65	38.73	0.98	1.90	9.34	8.14	1.38	2.83
120	38.46	37.29	1.05	2.27	9.60	7.27	1.43	2.53
s.e.d.	5.74	2.28	0.12	0.16	0.31	0.78	0.09	0.18
Indigo intercropping								
with indigo	43.18	38.49	1.10	2.33	9.27	7.97	1.36	2.75
without indigo	31.22	38.47	0.94	1.97	9.17	8.03	1.49	2.73
s.e.d.	2.88	3.43	0.07	0.08	0.62	0.52	0.11	0.12
ANOVA source of variation	*Significance of F value*							
Urea-N level (N)	ns	ns	ns	ns	ns	ns	ns	ns
Indigo treatment (I)	**	ns	ns	*	ns	ns	ns	ns
N × I	ns	ns	ns	ns	ns	ns	ns	ns

**, *, significant at the 1% and 5% levels respectively; ns = non-significant.

effect on the yield of tomato in 1995, and on the yield of soyabean in 1996, as shown by analysis of variance for each of the DS crops (Table 2). There was no significant interaction between WS inorganic N levels and indigo intercropping in terms of the DS crop yields indicating that the varying levels of inorganic N applied to the preceding rice did not influence the response of the DS crops to intercropped indigo either in 1995 or in 1996.

Wet season rice yields as affected by crop sequence, inorganic nitrogen level, and indigo green manure

Rice yields were significantly affected by both inorganic N levels and indigo green manure in 1994 and 1995. Cropping sequence had a significant interaction with indigo treatment in 1994 indicating that the response to indigo green manure during that year was not the same in all cropping sequences. In 1995, the interaction between cropping sequence and indigo treatment was not significant but the main effect of cropping sequence was significant. There was also a significant interaction between inorganic N and indigo in terms of rice yield.

Yields increased with rates of inorganic N up to 120 kg ha^{-1} in both the 1994 and 1995 WS (Table 3). In 1994, rice yields responded linearly to increasing rates of N with or without indigo green manure. The following year, rice yields with indigo did not respond to inorganic N application whereas those without indigo responded linearly to increasing N rates. Furthermore, indigo plots which did not receive inorganic N yielded higher than those given inorganic N at 120 kg ha^{-1} but no indigo green manure. Yields of indigo treatments averaged over all

Table 3. Grain yields of rice (t ha^{-1}) under four crop sequences (C) and with three rates of applied nitrogen (kg ha^{-1}, F) with and without indigo green manure (I) in the 1994 and 1995 wet seasons at Batac, Philippines.

		1994 wet season		1995 wet season	
Crop sequence	Nitrogen applied to rice	With indigo	Without indigo	With indigo	Without indigo
Rice–tomato	0	3.95	2.19	4.91	2.89
	60	4.31	3.17	5.20	3.89
	120	4.63	3.36	5.21	4.33
Rice–tobacco or soyabean†	0	3.68	1.90	4.81	2.45
	60	4.53	2.62	5.27	3.16
	120	5.42	3.79	4.95	4.22
Rice–maize	0	1.87	1.91	4.59	2.14
	60	3.21	2.27	5.30	3.29
	120	3.81	3.16	5.20	4.19
Rice–garlic	0	3.44	2.29	5.44	3.22
	60	4.41	3.07	5.41	4.00
	120	4.87	3.42	5.28	4.62
s.e.d.					
I means at each C × F		0.50		0.28	
I means at each C		0.29		0.16	
C means at each I		0.41		0.18	
I means at each F		0.25		0.14	
C means at each F		0.43		0.19	

†Tobacco 1994 and soyabean 1995.

cropping sequences and rates of inorganic N were about 45% higher than those of non-indigo treatments in both years.

Indigo enhanced rice yields in all cropping sequences except in the rice–maize sequence in 1994 (Table 3), but increased rice yields in all cropping sequences in the following year. The highest yield was obtained in the rice–garlic sequence.

Agronomic nitrogen use efficiency in rice

In 1994, ANOVA showed that ANUE was significantly affected by N treatments but not by the cropping sequence. However, there was a significant interaction between cropping sequence and N treatments indicating that the different cropping sequences exhibited different responses to the N treatments (Table 4). In 1995, the cropping sequence but not the N treatments significantly affected ANUE. There was also a significant interaction between cropping sequence and N treatments in that year (Table 4).

The average ANUEs obtained from indigo treatments in each of the cropping sequences were higher than those from non-indigo treatments in 1994 and 1995. In 1994, the highest ANUE was with indigo alone in the rice–tomato and rice–tobacco cropping sequences. In the same year, ANUEs in the rice–maize and rice–garlic cropping sequences were highest with indigo + 60 kg inorganic N ha^{-1}. In

Table 4. Effects of inorganic nitrogen with and without indigo green manure on the agronomic nitrogen use efficiency (ANUE, kg grain kg^{-1} applied N) of rice in various cropping sequences (C)† in the 1994 and 1995 wet seasons at Batac, Philippines.

	ANUE							
	1994 wet season				1995 wet season			
Nitrogen treatments (N)	Tomato	Tobacco	Maize	Garlic	Tomato	Soyabean	Maize	Garlic
Indigo-N alone	66.0	26.1	8.7	16.7	50.7	41.0	28.5	33.8
Indigo + 60 kg urea-N ha^{-1}	23.1	17.3	14.7	20.0	18.8	26.0	26.5	19.0
Indigo + 120 kg urea-N ha^{-1}	13.4	17.3	12.2	13.9	13.4	14.9	19.3	12.2
60 kg urea-N ha^{-1}	16.3	12.1	6.0	17.8	16.8	11.8	19.3	13.0
120 kg urea-N ha^{-1}	9.7	15.8	10.4	9.4	12.1	14.6	17.1	11.7
s.e.d. C means at each N	8.5				5.5			
s.e.d. N means at each C	6.9				4.3			
ANOVA source of variation	*Significance of F value*							
Crop sequence	ns				**			
N treatments	**				ns			
C × N	**				**			

†Dry season crop following rice shown in the table; ** significant at the 1% level; ns = not significant at the 5% level.

1995, ANUE was highest with indigo alone in each of the cropping sequences. Among the cropping sequences, rice–tomato exhibited the highest ANUE with indigo treatment followed by rice–soyabean in 1995 (Table 4).

DISCUSSION

The results presented in this paper show that indigo has a great potential in enhancing productivity of rainfed lowland rice-based cropping systems. It also showed potential for reducing chemical fertilizer input.

Indigo has a slow initial growth rate but growth can increase sharply four months after establishment (RLRRC, 1993). According to Garrity *et al.* (1994), a slow initial growth rate has distinct adaptive advantages as post-rice green manure, especially when it is established as a companion crop within an intercropping system. This was supported by the absence of any yield losses in the DS crops with an indigo intercrop. It is also consistent with farmer experience in the Ilocos Region, Philippines (Garrity *et al.*, 1994) and the published results in the rice–wheat cropping system (Mann and Garrity, 1994).

The average biomass production of intercropped indigo amounting to 2.94 t ha^{-1} was lower than the reported biomass production of an indigo monocrop. At the same site and at the same sowing rate (10 kg ha^{-1}), the biomass of a 180-day-old indigo monocrop was 5.6 t ha^{-1}. This indicates that DS crops generally suppressed the growth of intercropped indigo which also agrees with the studies conducted by Garrity *et al.* (1994). The amount of intercropped indigo N ranged

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from 38 to 71 kg N ha^{-1}, similar to those of azolla and sesbania grown for 50 to 70 days as pre-rice green manure (Ventura and Watanabe, 1993). Even though indigo is suppressed by the companion DS crop and despite its longer period of growth compared with other pre-rice green manures, it has the advantage that it can be established at minimal cost because the land is prepared for the companion food or cash crop (Garrity *et al.*, 1994) and there is no opportunity cost for the land because indigo is cultivated at the same time as the DS crop.

Increases in rice yield associated with indigo green manure were due primarily to additional N inputs and other nutrients recycled by the green manure crop. In 1994 and 1995, about 58 kg N ha^{-1} from indigo alone produced rice yields comparable with that obtained with an application of urea at 120 kg N ha^{-1}. At the same level of N inputs, indigo-N produced higher rice yields than urea-N (Fig. 1). A combination of about equal amounts of indigo and urea (58 + 60 kg N

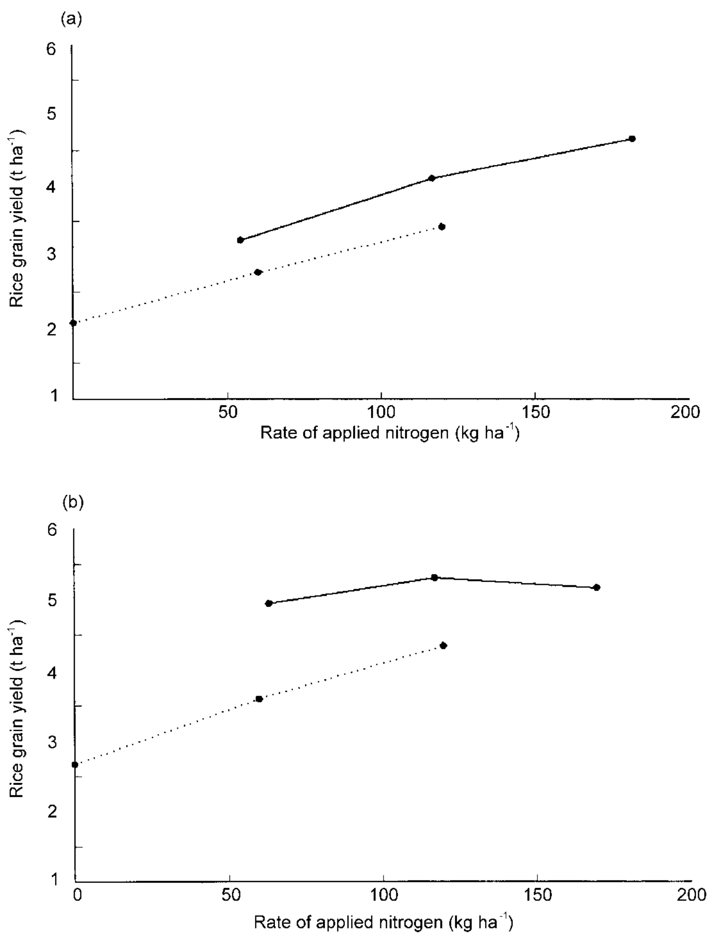

Fig. 1. Rice grain yields at varying rates of applied nitrogen with (—●—) or without (– -●- –) indigo in (a) 1994 and (b) 1995. S.e.d. indigo treatment means at each inorganic N level = 0.25 in 1994 and 0.14 in 1995.

ha^{-1}) had a yield advantage over urea alone (120 kg N ha^{-1}) of 0.7 t ha^{-1} in 1994 and 1.0 t ha^{-1} in 1995. Part of this yield increase may result from improved N-use efficiency with indigo alone and indigo in combination with urea compared with urea alone. The low N-use efficiency of the inorganic N fertilizer may be due to high N losses from the different cropping systems in the province. Tripathi *et al.* (1997) reported losses up to 549 kg N ha^{-1} for one year in the area. The major reason for the improvement in rice yield would therefore have been the reduced N losses and improved congruence of N supply and crop N demand when green manure was added.

Green manure may influence N supply and a wide range of other soil properties (Bouldin, 1988). The results of this study show that indigo green manure had effects on soil productivity in addition to supplying N. In Fig. 1, no amount of urea N without indigo would give a yield equal to that obtained when N is no longer a yield-limiting factor. Rice grain yields without green manure were within the range of 3 t ha^{-1}, when enough N was added to eliminate N as a yield-limiting factor. With green manure yields were about 4 t ha^{-1}. Thus the yield potential with optimum fertilizer N is different in the presence or absence of indigo.

Results obtained from the experiment suggest that there were non-N benefits from indigo green manuring. Some of these positive effects from indigo may result from an increase in P availability. Unfortunately, P was not measured in this study, but at MMSU the soil is alkaline and the available P is very low (<3 mg P kg^{-1} soil), so the 15 kg P ha^{-1} supplied may not be sufficient. The indigo may have mobilized P reserves from pools that are less available to rice, either chemically or simply from greater depths. Organic manures increase P availability through acidifying and chelation mechanisms (Black, 1968). More research is therefore needed on the influence of indigo green manure on the soil properties of the different rice cropping systems of the Ilocos Region so that the benefits from green manuring are maximized.

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