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Effect of crop management practices on Nitrogen (N) availability and N use efficiency in direct wet-seeded rice

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1 SUMMARY

The effect of crop management practices on nitrogen (N) availability and N use efficiency in lowland rice (*Oryza sativa* L.) was investigated at International Rice Research Institute (IRRI) and PhilRice (Muñoz, Nueva Ecija) in the Philippines. The experimental design was randomized complete block with four replications. The treatments were factorial combinations of crop and N fertilizer management practices. Four experiments with wet direct seeded rice were conducted during 2003 and 2004 dry seasons. The results indicated that indigenous N supply (INS) was not significantly different between methods of weed control. Weed control using rotary weeding significant increased extractable soil ammonium during 2004 dry season although N uptake at maturity was not significantly higher in these treatments at both sites. The agronomic efficiency of applied N (AEN) varied between sites, N and crop management practices. At IRRI, AEN in treatments with herbicide application was significantly higher than in rotary weeding. It was also revealed from the study that broadcast and hill sowing were equally effective in grain yield, although hill sowing offers more opportunity to reduce seed rate and flexibility for mechanical weed control.

2 INTRODUCTION

Rice cultivation by direct seeding is viewed as both cost-saving and laborsaving practice. It is becoming increasingly popular alternative to transplanting in some regions of Asia due to low labor costs and availability of short duration rice varieties that allows intensive rice cultivation (Flin and Mandak, 1986; Pandey and Velasco, 2002). In the resent years, changes in rice production technology that involved the use of drum seeder, mechanical weeding using rotary weeder and availability of selective herbicides have improved the desirability for direct seeding (De Datta and Nantasomsaran, 1991; Pandey and Velasco, 2002). In irrigated areas, wet direct seeding that involve broadcast, spot seeding and row seeding by drum seeder are the common sowing techniques (Ho, 1995, Jaffar *et al*., 1995, Bo and Min, 1995, Yamauchi, 2000).

Under direct seeding, weeds have been found to be the biggest biological constraint because they emerge simultaneously with rice seedlings. The recommended strategies for weed management in this case include chemical (herbicides), mechanical (rotary weeding) and manual (Balasubramanian and Hill, 2002). Farmers who use direct seeding however rely more heavily on chemical weed control (Erguiza *et al*., 1990) although it has been hinted that prolonged use of the same herbicide may lead to infestation of selective tolerant weed species (Balasubramanian and Hill, 2002). Reports on the use of mechanical weeding by rotary or cone weeder which churns and incorporates weeds into the soil has shown good results in transplanted rice (Uphoff, 2001; Thiyagarajan *et al*., 2002 and Balasubramanian, 2005). It was however not substantiated whether the increase in yield with mechanical weeding was due to soil disturbance by mechanical weeding that improve soil aeration and N availability through aerobic decomposition of organic materials or due to other factors. The present study was therefore intended to evaluate the impact of different wet direct seeding techniques and methods of weed control on N availability and N use efficiency. The specific objectives are (1) to determine the effect of wet direct seeding weed control methods and N fertilizer management on crop performance, (2) to determine the effect of weed control methods on fertilizer N use efficiency, and (3) determine the effect of wet direct seeding techniques and weed control on N availability

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3 MATERIALS AND METHODS

Four experiments were conducted during 2003 and 2004 dry seasons at International Rice Research Institute (IRRI) experimental station (14°11'N, 121°15'E, 21 m altitude) and PhilRice experiment station in Muñoz, Nueva Ecija (15°45' N, 120°56' E, 48 m altitude). The soils at IRRI is Maahas clay classified as an Aquandic Epiaquoll with pH 7.0, 13% sand, 42% silt, 45 % clay, 1.5% organic C, 0.1% total N, 6.0 cmol (+) kg^{-1}, 6.0 mg kg^{-1} Olsen P, 0.2 mg kg^{-1} Zn, 39.0 meq/100 g CEC, exchangeable Na, K, Ca and Mg of the soil were 1.2 cmol (+) kg^{-1}, 1.6 cmol (+) kg^{-1}, 17.8 cmol (+) kg^{-1} and 13.3 cmol (+) kg^{-1}, respectively. The mean solar radiation at IRRI was 18.7 MJ M^{-2} d^{-1}, mean monthly rainfall was 23.0 mm and mean monthly temperature was 26.2 °C, CEC/Clay ratio for this site was 0.9 (Montimorillonite clay mineralogy). The soil at PhilRice is classified as Vertic Tropaquept with pH 6.7, 3% sand, 41% silt, 56% clay, 1.2% organic C, 0.1% total N, 4.0 mg kg^{-1} Olsen P, 36.7 cmol (+) kg^{-1}, 0.6 mg kg^{-1} Zn, 36.7 mew/100 g CEC, exchangeable Na, K, Ca, Mg of 0.6 cmol (+) kg^{-1}, 0.2 cmol (+) kg^{-1}, 15.7 cmol (+) kg^{-1}, 5.8 cmol (+) kg^{-1}, respectively. Mean solar radiation at PhilRice was 24.2 MJ M^{-2} d^{-1}, mean monthly rainfall was 4 mm and mean monthly temperature was 27.1 °C, CEC/clay ratio for this site was 0.7 (mixed montimorillonite clay mineralogy).

The experimental design was randomized complete block with four replications. The treatments were factorial combination of N and crop management practices. During 2003 dry season, N management treatments were (1) N control and, (2) split N application with 35 Kg N ha^{-1} at 21 days after seeding (DAS), 35 kg N ha^{-1} at 35 DAS, 45 kg ha^{-1} at 45 DAS and 10 kg N ha^{-1} at 63 DAS. During 2004 dry season, N management involved (1) N control, (2) N fertilization by fixed rate and timing at 140 kg N ha^{-1} (50 kg N ha^{-1} at 21 days after seeding (DAS), 40 kg N ha^{-1} at 35 DAS, and 50 kg N ha^{-1} at 49 DAS), and (3) no basal N application and real time N management based on leaf color chart (LCC) with reading taken at 7 days interval. The critical level for LCC reading was 3. Crop management practices involved broadcast sowing with herbicide (standard practice), hill sowing with herbicide and hill sowing with rotary weeding. During 2005 dry season, additional treatment that had hill sowing with rotary plus hand weeding was included.

One lowland transplanted variety (PSBRc-82) was used at both sites in all experiments. The seed rate for broadcast 80 kg/ha and 50 kg/ha for hill sowing during 2003 dry season and 40 kg ha^{-1} for hill sowing during 2004 dry season. The seeds were pregerminated before sowing in well puddled and leveled plots at a spacing of 20 cm x 20 cm for hill sowing. Uniform P, K and Zn was applied to all plots to prevent deficiency at the rate of 30 kg P/ha as triple super phosphate and 10-kg Zn at both sites, 20 kg K ha^{-1} and 50 kg ha^{-1} as potassium chloride at IRRI and PhilRice respectively. Weed control in herbicide treatments was done using herbicide Pretilachlor 300 EC (Sofit) applied at three DAS. Weed control in other treatments were done using rotary weeder pushed through the plots at 16, 27 and 34 DAS.

Plant growth was assessed from sequential plant sampling done at 21, 35, 49, and 63 DAS for the 2005 dry season and 35, 49, and 63 DAS for 2005 dry season in fertilized treatments only. The sampling area was 0.48 m^2 for the first sampling in 2004 dry (2 areas of 0.4 x 0.6 m or 12 hills in hill-sown treatments) and 0.32 m^2 (2 areas of 0.4 x 0.4 m or 8 hills in hill-sown treatments) for the proceeding samplings.

Soil samples (top 20 cm) were collected at 1 day before sowing (DBS) in all plots, 23 days after sowing (DAS) and 35 DAS in treatments with no N application for the analyses of extractable soil ammonium (Keeney and Nelson, 1982). The anaerobic N mineralization was determined at 23 DAS in treatments with no N addition (N omission plots) following procedures described by Keeney and Nelson, 1982). Indigenous N supply was determined from N accumulation in grains and straw at crop maturity in N omission plots i.e. treatments with no N application (Doberman *et al.* 2003). The data obtained were subjected to analysis of variance (ANOVA) using SAS (SAS Inst., 1999) statistical software.

4 RESULTS AND DISCUSSION

4.1 Nitrogen supply as affected by soil disturbance by rotary weeder: The trend in extractable soil ammonium was not significantly different among crop management practices in each sampling time during 2003 dry season (Table1). Generally, extractable N one day before seeding (1 DBS) was higher than the preceding sampling at IRRI during 2003 DS and 2004 DS while the reverse trend was observed in PhilRice. This difference could be attributed to differences in clay mineralogy between the two sites. During 2004 dry season, soil disturbance by rotary weeding significantly increased extractable ammonium 35 DAS at both sites. However, despite higher extractable soil ammonium at 35 DAS, shoot growth rate between 35 and 49 was not significantly different between crop management practices in treatments with no N additions (Table 3). Lack of significant increase in shoot growth rate despite increased N availability due to rotary weeding implies an inefficient utilization of the available N for growth. The results in N uptake from N omission plots (INS) were also not significantly higher for all crop management practices used (Table 2). The failure of increased soil ammonium from rotary weeding to resulting greater accumulation of N in the plant at maturity might be due to losses of ammonium, through denitrification processes.

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Crop management practices had no significant effect on anaerobic mineralizable N at both sites and seasons (Table 2). However, during 2003 and 2004 dry seasons, IRRI showed to have significantly higher amounts of anaerobic mineralizable N than PhilRice. This could be due to higher organic C at IRRI than PhilRice. Sahrawat (1983) and Narteh and Sahrawat (1997) reported the same phenomenon in wetland soils of the Philippines and West African soils, respectively, suggesting that a reasonable prediction of potentially anaerobic mineralizable N in wetland rice culture could be made from organic matter content of the soil. The difference in mineralizable N between IRRI and PhilRice could also be due to the effect of (differences in clay mineralogy and) exchangeable K^+ on ammonium fixation between the two sites. Mixed kaolinite clay mineralogy and higher exchangeable K^+ at IRRI suggest that most of the exchangeable sites were occupied by K^+ and that kaolinite is unable to fix NH_4^+. PhilRice on the other hand have mixed montimorillonite and low exchangeable K^+ such that N mineralized from organic sources is easily fixed by clay minerals. Keerthisinghe *et al.* (1985) also reported that soils at PhilRice have appreciable amount of vermiculite, which have greater fixing capacity for ammonium

Table 1: Extractable ammonium N as affected by crop management practices

Crop management practices	**Extractable N (mg kg^{-1})**					
	2003 DS			**2004 DS**		
	IRRI	**PhilRice**	**Difference**	**IRRI**	**PhilRice**	**Difference**
	1 DBS					
Broadcast + herbicide	6.8	2.1	4.7*	8.8	2.8	6.0*
Hill sowing + herbicide	6.4	3.7	2.7*	8.6	2.4	6.2*
Hill sowing + rotary weeding	6.1	3.3	2.8*	7.4	2.4	5.0*
Hill sowing + rotary and hand weeding				8.5	2.3	6.2*
LSD 5%	ns	ns		ns	ns	

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	21 DAS			23 DAS		
Broadcast + herbicide	4.4	5.4	-1.0ns	6.1	6.3	-0.2ns
Hill sowing + herbicide	4.0	7.6	-3.6*	9.3	5.1	4.2*
Hill sowing + rotary weeding	5.1	7.3	-2.2ns	6.4	6.9	-0.5ns
Hill sowing + rotary and hand weeding				8.2	7.3	0.9ns
LSD 5%	ns	ns		ns	ns	
	35 DAS					
Broadcast + herbicide	2.2	2.7	-0.5ns	2.3	5.0	-2.7*
Hill sowing + herbicide	2.0	4.0	-2.0ns	3.5	4.5	-1.0ns
Hill sowing + rotary weeding	4.2	3.5	0.7ns	5.7	7.7	-2.0ns
Hill sowing + rotary and hand weeding				6.9	6.9	0ns
LSD 5%	ns	ns		2.2		

DBS = days before seeding, DAS = days after seeding, DS = dry season, ns = non significant, * = significant at 5% probability

Table 2: Effect of site and crop management practices on N availability

Crop management practices	**Indigenous N supply (kg N ha^{-1})**					
	2003 DS			**2004 DS**		
	IRRI	**PhilRice**	**Difference**	**IRRI**	**PhilRice**	**Difference**
B + herbicide	30	56	-26*	57	44	13*
H + herbicide	28	53	-25*	43	36	7ns
H + rotary weeding	34	46	-12*	47	38	9ns
H + rotary plus hand weeding	-	-		44	39	5ns
LSD 5%	ns	ns		ns	ns	
Crop management practices	Anaerobic N mineralization (mg kg^{-1}day^{-1})					
	2003 DS			2004 DS		
	IRRI	PhilRice	Difference	IRRI	PhilRice	Difference
B + herbicide	6.8	3.0	3.8*	7.0	3.7	3.3*
H + herbicide	8.5	1.9	6.6*	7.1	2.8	4.3*
H + rotary weeding	9.4	3.0	6.4*	5.9	3.4	2.5*
H + rotary plus hand weeding	-	-		6.0	2.5	3.5*
LSD 5%	ns	ns		ns	ns	

DS = dry season, ns = non significant, B = broadcast, H = hill sowing, * = significant at 5% probability

4.2 Crop performance as affected by soil disturbance by rotary weeder: During 2003 dry season, crop management practices had no significant effect on shoot growth rate between 35–49 DAS at both sites (Table 3). During 2004 dry season, broadcast sowing had significantly higher growth rate than hill sowing at IRRI (Table 3). At PhilRice, variation in shoot growth rate was due to crop and N management practices. At this site, broadcast sowing had significantly higher growth rate with split N application than LCC based N management. Shoot growth rate for hill sowing with herbicide and hill sowing with rotary weeding were not significantly different between split N application and LCC based N management indicating the need to refine the critical level for LCC based on method of seedling establishment.

The results from this study indicated that crop management practices used had no significant effect on grain yield at IRRI during 2003 dry season (Table 4). At PhilRice on the other hand, broadcast sowing gave the grain yield of 7.9 t ha^{-1}, which was significantly higher than other crop management practices tested. Higher grain yield in broadcast sowing was mainly due to higher number of tillers, panicles and larger number of filled grains (Table 5). During 2004 dry season, crop management practices resulted to comparable yield at both sites (Table 4). Grain yield comparison between the two sites indicated that PhilRice had significantly higher yield than IRRI using broadcast sowing. However, other crop management practices were not statistically different between the two sites. Despite the fact that seed rate used for broadcast sowing was twice as much compared to hill sowing, grain yield for broadcast and hill sowing were comparable except at PhilRice in 2003 dry season (Table 6). This indicates that both seeding methods could be used and arrives at the same grain yield. Soil disturbance by rotary weeding had no significant effect in grain yield in the same site and between sites. Elsewhere, it was reported that weed control by rotary weeding increases grain yield under transplanted rice culture under intermittent water management (Uphoff, 2001; Thiyagarajan *et al.*, 2002). In the present study, methods of weed control had no significant effect on grain yield in direct seeded rice possibly because water management for the direct seeded experiment was continuous flooding as compared to intermittent irrigation in the former studies. In direct seeded rice culture, the choice of the weed control method will therefore depend on the financial status of the farmer as well as the economics associated with it as both weed control methods had the same effect on grain yield although hill sowing results to reduced seed rate and flexible to weed control methods.

Table 3: Crop growth rate as affected by crop management practices between 35 – 49 DAS

Crop management practices	**Shoot growth rate (g m^{-2} d^{-1})**					
	2003 DS		**2004 DS**			
	IRRI	**PhilRice**	**IRRI**	**PhilRice**		
	Mean	**Mean**	**Mean**	**Split N**	**LCC**	**Difference**
Broadcast + herbicide	16.6	14.3	28.1	16.8	11.5	5.3**
Hill sowing + herbicide	13.9	13.5	19.4	10.6	11.4	-0.8ns
Hill sowing + rotary weeding	13.4	12.9	18.0	10.4	10.0	0.4ns
Hill sowing + rotary and hand weeding			16.0	11.2	9.8	1.4ns
LSD 5%[b]	ns	ns	3.6	1.8		

a = LSD 5% for comparing means along the rows, b = LSD 5% for comparing means along the columns, ** significant at 1% probability, ns = non significant, DS = dry season

Table 4: Effect of site and crop management practices on grain yield

Crop management practices	**Grain yield (t ha^{-1})**		
	IRRI	**PhilRice**	**Difference**
	2003 DS		
B + herbicide	7.1	7.9	0.8 *
H + herbicide	6.5	6.9	0.4ns
H + rotary weeding	6.8	6.5	0.3ns
LSD 5%	ns	0.7	
	2004 DS		
B + herbicide	7.2	7.5	0.3ns
H + herbicide	7.1	7.2	0.1ns
H + rotary weeding	7.0	7.4	0.4ns
H + rotary and hand weeding	7.3	7.3	0.0ns
LSD 5%	ns	ns	

B = broadcast sowing, H = hill sowing, ns = non significant,, * = significant at 5% probability, DS = dry season

Table 5: Effect of crop management practices on yield components (IRRI and PhilRice 2003 DS)

Crop management practices	**Site**	**Yield components**				
		Tillers/ m^{-2}	**Panicles/ m^{-2}**	**Straw yield ($t\ ha^{-1}$)**	**1000 grain weight**	**Filled grains/ m^{-2}**
B + herbicide	IRRI	699	664	5.2	23.7	26773
H + herbicide	IRRI	350	329	3.5	24.0	19121
H + rotary weeding	IRRI	385	354	3.7	24.0	23584
LSD 5%		32	31	0.8	ns	3205
B + herbicide	PhilRice	907	891	9.0	23.5	36358
H + herbicide	PhilRice	472	443	7.2	22.8	27330
H + rotary weeding	PhilRice	515	490	6.7	22.1	26571
LSD 5%		91	91	1.0	0.8	3754

B = broadcast sowing, H = hill sowing, DS = dry season

Table 6: Single degree of freedom analyses for the effect of crop management practices on grain yield

Crop Management Practice	**Grain Yield (t/ha)**			
	IRRI 2003 DS	**PhilRice 2003 DS**	**IRRI 2004 DS**	**PhilRice 2004 DS**
Weeding method				
Herbicide	6.5	6.9	7.1	7.2
Rotary weeding	6.8	6.5	7.2	7.4
F-value	0.25 ns	1.82 ns	0.51 ns	0.26 ns
Seeding method				
Broadcast sowing	7.1	7.9	7.2	7.5
Hill sowing	6.6	6.7	7.1	7.3
F-value	0.87 ns	20.12**	0.48 ns	0.91ns

Note: ns = non significant; ** significant at 1% probability; DS = Dry Season

4.3 Crop performance as affected by N application: The results on N use efficiency under different crop and N use management practices are shown in table 7. During 2003 dry season, there was no significant difference in N uptake for the crop management practices used at both sites (Table 7). .However, during 2004 dry season, mechanical weeding significantly increased N uptake over hill sowing with herbicide at IRRI and a comparable values at PhilRice. Despite higher N uptake at IRRI, grain yield at this site was not significantly different between hill sowing with herbicide and hill sowing with rotary weeding. The AEN for the two treatments were also comparable at PhilRice while at IRRI, the variation in AEN was due to crop and N management practices (Table 7). At IRRI, mechanical weeding resulted to significantly lower AEN in LCC based N management compared to hill sowing with herbicide. The results indicated that weed control using herbicides results to greater N use efficiency using LCC as compared to split N application. This needs further evaluation as weed control using rotary cone weeder has provided better results in water saving techniques in rice production (Uphoff, 2001).

Table 7: Effect of crop management practices on N uptake and agronomic efficiency of applied N (AEN)

Crop management practices	**N uptake (kg N ha^{-1})**		**AEN (kg grain/kg N applied)**			
	IRRI	**PhilRice**	**IRRI**			**PhilRice**
	2003 DS					
Broadcast sowing + herbicide	114	139	38			27
Hill sowing + herbicide	94	130	33			21
Hill sowing + rotary weeding	96	112	32			22
LSD 5%	ns	ns	ns			ns
	2004 DS					
	IRRI	**PhilRice**	**IRRI**			**PhilRice**
			Split N	LCC	Difference	Mean
Broadcast sowing + herbicide	121	137	28	32	-4*	29
Hill sowing + herbicide	104	110	29	34	-5*	28
Hill sowing + rotary weeding	122	112	27	24	3ns	28
Hill sowing + rotary and hand weeding	120	110	32	27	5*	28
LSD 5%	13	13	4			ns

Note: DS = Dry Season; LCC = Leaf Color Chart; * Significant at 5% probability

5 CONCLUSION

Rice farmers can use rotary weeding instead of herbicide in controlling weeds and achieve the same grain yield. With regard to seeding methods, farmers who use direct seeding could benefit by switching from broadcast sowing to hill sowing as the later results to reduced seed rate and offers more flexibility to methods of weed control. It was also revealed from this study that the two methods of weed control used had no significant effect N availability in soil under continuous flooding. Fertilizer N management using LCC seem to be an alternative option to split N application as it improves N use efficiency. However, N application using LCC need to be further refined based on the method of seedling establishment as the use of the same critical level for both seedling establishments may overlook the fact that plants in these methods exhibit different growth constraints. Furthermore, rice performance using herbicide and rotary weeding needs more evaluation in other water management regimes.

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