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EVALUATION OF DRILL SEEDING PATTERNS AND NITROGEN MANAGEMENT STRATEGIES FOR WET AND DRY LAND RICE

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Abstract

Many Asian farmers are shifting from rice transplanting to direct seeding because the latter requires less labour, time, drudgery, and cultivation cost. Direct seeding is usually practiced in either wet or dry land preparation depending on water availability. The present study aimed at evaluating the potential of single and paired rows drill seeding patterns and five N management strategies on crop productivity, N use-efficiency, and apparent N balance. The experiment was laid out in a split plot design with two seeding patterns as main plots and five N treatments as subplots with three replications. Drill seeding did not affect grain yield, water, and N use-efficiencies and N balance. Grain yield increased with LCC-based N management with the lower N fertilizer input. Soil available N after 2 years of rice cropping was similar to the amount at the beginning indicating most of applied fertilizer N was lost.

Keywords: Drill seeding, planting pattern, N-use efficiency, and N balance.

Introduction

Many Asian farmers are shifting rice establishment method from transplanting in puddle soil to direct seeding in either puddle soil or dry soil after dry tillage because the latter requires less labour, time, drudgery and cultivation cost (Bhushan *et al*., 2007; Pandey and Velasco, 2002; Yamauchi *et al*., 2000). Direct seeding requires only 34% of the total labour requirement of transplanted rice (Ho Nai-Kin and Romli 2002) and 29% of the total cost of transplanted rice production without any yield loss. Farmers usually practice direct seeding of rice by broadcast method. It can also be done by drilling the seeds in line either manually or with the use of drill machine by sowing in line either manually or with the use of simple plastic made implement known as drum seeder (Balasubramanian *et al*., 2003). Drill seeding, a variant of direct seeding, is

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sowing the seeds in rows at specified seed rate, depth, and covers those with soil under dry or moist condition. This method of rice establishment substantially reduces labour requirement, improves emergence of seeds, and reduces lodging to less than 10% (Bakker *et al*., 2002). Combined with fertilizer application and effective control of weeds through the use of herbicides and mechanical weeder, drill-seeding can increase grain yield by 25% (Devnani, 2002). The benefit of direct-seeding of rice and development of mechanical device or power operated machineries for tillage and seeding purposes have created an opportunity to use different planting methods of crop establishment in direct-seeded rice cultivation. Single-row drill-seeder, both manual and mechanical, is traditionally used for direct seeding cultivation.

Nitrogen fertilizer management in emerging direct-seeded rice cultivation is important and a challenging task to achieve high yield and increased N use efficiency (NUE). In general, N uptake is less than 40% of the total N applied in rice cultivation (Ladha *et al*., 2005). The low level of N utilization is due to high N losses through volatilization, denitrification, runoff, and leaching. Application of N not synchronized with plant need leads to high N losses, low yield, and poor grain quality. Nitrogen uptake patterns over the growing season depend on the availability of soil N, timing of fertilizer application, and amount of fertilizer N available (Ladha *et al*., 2005).

Crop demand and N supply should be synchronized taking into the account of effective indigenous N supply, and crop uptake under consideration to increase N fertilizer use efficiency. Crop demand for N can be predicted by plant-based N management strategies, which requires thorough monitoring of the N status of the rice crop at different growth stages. In recent years, Leaf Colour Chart (LCC) has become an effective tool to estimate leaf N status – an indicator of plant N demand (Ladha *et al*., 2005)

Information on NUE and N balance under intermittent irrigation management approach are imperative in making sound fertilizer recommendations that reduce N losses and maintain potential yield of direct-seeded rice. Research findings on NUE and N balance in paired and single-row planting methods in drill-seeded rice are, however, meager. This paper presents the results of a field study conducted to evaluate the potential of single and paired row drill seeding patterns and five N management strategies on crop productivity, N use-efficiency, and apparent N balance.

Materials and Method

Experimental site

A field experiment was conducted at the experimental farm of the International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines during the wet season (WS) of 2003 (June-October) and the dry season (DS) of 2004 (January-May). Geographically, the site is located within a major irrigated rice production area at 14^o 11´ N latitude and 121^o 15´ E longitude. The textural class of the soil is clay and taxonomically classified as an Andaqueptic Haplaquoll (USDA Soil Taxonomy) with a bulk density 0.92 g cm^{-3} in the first 60 cm soil depth. The soil had a 6.43 pH, total N 1.6 g/kg, organic C 19.3 g/kg, Olsen P 6.63 mg/kg, and available K 8.2 meq/kg. Available Zn content was 0.51 mg/kg, while cation exchange capacity was 31 meq/100g. The total rainfall from June 2003 to May 2004 was 1397 mm about 78% of which occurred from June to November. Mean maximum and minimum temperatures were 31.4 and 24.4 ^{o}C during the wet season (June to October, 2003) and 30.9 and 23.6 ^{o}C during the dry season (January to May, 2004), respectively.

Experimental design and treatments

The experiment was laid out in a split-plot design with two drill seeding patterns as main plots (S_1 and S_2) and 5 N management strategies as subplots (N_1 to N_5) with three replications. The unit plot size was 220 m^2 (20 m × 11 m) surrounded by bunds, and **c**anals were made in between two bunds for irrigation and drainage. An IRRI seed drill attached with a 12 rows seeder mounted tractor was used for sowing. The details of main plot and sub plot treatments are as follows:

Single row seeding (S_1): Dry seeds at 65 kg/ha were drilled in rows at 20 cm spacing and covered with soil.

Paired rows seeding (S_2): Dry seeds at 65 kg/ha were drilled with a drill machine in paired rows at 10-cm spacing between rows and 30-cm spacing between pair of rows and covered with soil.

N treatment 1 (N_1): No fertilizer N applied.

N treatment 2 (N_2): Prilled urea at 120 kg N/ha in the wet season and 150 kg N/ha in dry season was broadcast in three splits - 30% each at planting and maximum tillering stage, and 40% at panicle initiation stage,

N treatment 3 (N_3): Leaf colour chart (LCC)-based nitrogen application−Pilled urea was broadcast using a LCC reading (Balasubramanian *et al*., 2002). The leaf colour of fully expanded youngest leaf of each of 10 selected healthy hills were measured by LCC at 7-10 d intervals starting 25 d after sowing (DAS) till flowering stage (10% plants flower). If the leaf colour fell between two colour strips of LCC, than the mean of the two colour strip numbers was taken as the LCC reading. The critical LCC value for drill-seeded rice was 3 and 3.5 during the wet and dry seasons, respectively. Whenever the average of 10 LCC readings fell below the critical value fertilizer N at 23 kg/ha and 30 kg/ha was applied during the wet and dry seasons, respectively.

N treatment 4 (N_4): Prilled urea at 120 kg N/ha in wet and 150 kg N/ha in dry season broadcast in two splits - 40% at 10 days after emergence (DAE) and 60% at panicle initiation (PI) stage.

N treatment 5 (N_5): Prilled urea at 120 kg N/ha in wet season and 150 kg N/ha in dry season was broadcast in two splits - 80% deep placed at planting , and the 20% applied based on LCC reading.

Field and crop management

Soils were ploughed under dry conditions. The quantity of crop residue that ploughed down in wet season was not determined. Drill seeding (var. IR73885) was done on 4 July 2003 for the wet season and 7 Feb. 2004 dry season. Plants were thinned at 15 DAS to get a uniform plant stand. Phosphorus as solophos and zinc as $ZnSO_4$ were applied in all plots at 40 kg/ha and 10 kg/ha, respectively, during final harrowing. Potassium as KCl was likewise applied at 40 kg/ha in two equal splits (50 % at planting and 50% at PI). Standing water was drained at 10 d after sowing in order to facilitate seed germination and seedling establishment. Irrigation was done whenever soil moisture tension at 15-cm depth reached 0 KPa starting from 15 DAS and continued until 15-d before harvesting. The depth of water applied was measured using a flow meter and maintained 5 cm at each irrigation. Weeding was done three times by hand weeding and by applying post-emergence herbicide. Other plant protection measures were carried out as and when required. Crops were harvested at maturity during 25–26 October 2003 and 27–28 May 2004 in wet and dry seasons, respectively.

Plant, soil and water sampling, and analysis

Grain and straw yields were obtained from 12 m^2 sampling quadrate per plot located approximately 2 m from the border. Grain yield was reported at 0.14 g H_2O/g fresh weight. Rice plants from four 0.12 m^2 one from each of the four sides of grain harvest area were collected at ground level for measuring yield component. Grain and straw sub-samples were dried at 70 ^oC for 2 days and then finely ground to pass through a 0.5 mm sieve. Nitrogen content in the sub-samples was determined separately by digesting with concentrated H_2SO_4, followed by analysis for total N by micro-Kjeldahl method (Yoshida, 1976).

Composite soil samples from three spots in each plot at 0–20, 20–40, and 40–60- cm depth were collected using a 5 cm diameter core sampler before planting and after harvesting of crop. Soil from a plot at each depth was mixed, placed in an icebox, transported to the laboratory, and stored in a freezer till soil extracted with 2 N KCl to inhibit N transformation processes. Ammonium- and nitrate-N were extracted with 2 N KCl. Ammonium-N in the KCL extract was determined with the salicylate method (Keeney and Nelson, 1982; Kempers, 1986), while nitrate-N was measured using the copperized Cd reduction method (Dorich and

Nelson, 1984; Keeney and Nelson, 1982). The light absorbance of the solutions was determined at a wavelength of 540 nm (Jackson *et al*., 1975). Soil moisture content was determined gravimetrically. Concurrently, samples were collected for bulk density determination. Total N, total C, available P, K, and Zn were analyzed in a 200g sub-sample from a composite sample collected at 0–20cm depth before planting and after harvesting.

Water samples from different irrigation channels were collected at maximum tillering, flowering, and harvesting stages of crop growth in both seasons for the determination of NH_4^+-N and NO_3^--N. A composite water sample was stored in an airtight bottle in a freezer until analysis.

Data analysis

N-use efficiency was expressed as (a) agronomic N-use efficiency (AE_N), (b) recovery N-use efficiency (RE_N), (c) physiological N-use efficiency (PE_N), and (d) partial factor productivity of N (PFP_N) as described by Ladha *et al*. (2005).

The amount of water applied was measured by an axial flow meter. Water-use efficiency was calculated as the ratio of yield (kg/ha) to total water applied (TWU) (mm/ha) and expressed in kg/mm.

The data were statistically analyzed by analysis of variance (ANOVA) and the comparison of treatment means was made by least significant difference (LSD) following by IRRISTAT 5.0 programme (IRRI, 2005).

Results and Discussion

Grain yield and yield-contributing parameters

Grain yields were not significantly different between single row (4761 kg/ha) and paired row (4529 kg/ha) in both the seasons and likewise yield parameters remained unchanged.

Changing row spacing by keeping same number of plants per unit area to modify the diurnal exposure of individual plants to the various elements of the microclimate did not provide significant benefit to grain yield.

Nitrogen management significantly influenced grain yield and yield components during both seasons (Table 1). In wet season, N_2, N_3, N_4, and N_5 had similar yields and yield parameters, which were significantly higher from no N fertilization (N_1). This implies that various N timings and LCC aided N management were not crucial in the wet season. However, the results indicated the possibility of reducing N input with no yield loss by synchronizing time of application with leaf N status using the LCC.

During dry season, the LCC based N management (N_3) had the highest yield of 5956 kg/ha followed by N_2, N_5, N_4, and N_1. The differences between N_3, N_4, and N_1 were significant (Table 1). Similar trend was also observed in case of yield components. These results implies that better synchrony between N application and plant demand is important in dry season for obtaining higher yield, which could be achieved with the use of LCC. Results also show that N_2 and N_5 were superior to N_4 treatment. More sterility in case of N_4 indicated that plants might have suffered with N deficiency at later growth stages. Buresh *et al.* (2001) compared various N management techniques for rice and obtained the highest yield when N was applied following LCC method. This study also suggested that a lower N dose at an early stage of growth (without basal) and a higher dose at later stage were effective. Linwattana (2001) reported that yield and agronomic parameters of direct-seeded rice gave better response to N application when 60 kg/ha N was applied in three splits−15 kg each at 15 and 30 days after emergence (DAE) and the remaining 30 kg at 45 DAE or at PI. These observations tend to indicate that N is critically needed possibly between active tillering and panicle initiation.

Water input and water-use efficiency

Drill-seeding pattern did not influence the amount of irrigation water applied and water-use efficiency (WUE) during both seasons (data not shown). The amount of water applied during wet season was 287 and 325 mm/ha for single row and paired rows seeding method, respectively. These amounts were about threefold lower than the amount applied in the dry season. The results likewise indicated that changing seeding pattern from the usual single-row drill seeding to paired-row drill seeding may not increase crop water requirement provided the seeding rate remains unchanged.

Nitrogen-use efficiency

Drill seeding pattern did not influence any of the N efficiency parameters (AE_N, RE_N, PE_N, and PP_N). However, N management strategies and interaction effect of drill seeding pattern and N management significantly affected all N-use efficiency parameters in both seasons. During wet season, AE_N was the highest in case of LCC based N management (N_3) strategy and was similar with that of N_2 strategy (Table 2). During dry season, N_3 had the highest AE_N, which was significantly higher than N_2, N_4, and N_5. The results indicated that irrespective of seeding pattern, higher N-use efficiency can be achieved through proper synchronization of the time of N fertilizer application and plant N demand using leaf colour. The interaction effects of seeding pattern and N management strategies on RE_N and PE_N during wet season are shown in Table 3. The RE_N in N_3 management strategy with paired-row drill-seeding was significantly higher than those in other N management strategies with both single-row and paired-row seeding patterns. Similarly, the lowest RE_N was found in N_5 management strategy with paired-row seeding pattern. The RE_N in other N management strategies did not vary significantly irrespective of drill-seeding patterns.

Table 1. Effect of nitrogen management strategies on yield and yield contributing parameters during the wet season and dry season.

Nitrogen management strategy	Wet season 2003							Dry season 2004						
	Grain yield (kg/ha)	Number of panicles/ m^2	Number of filled spikelets/ $panicle^{-1}$	Number of grains per square meter	Plant height (cm)	Panicle length (cm)	1000-grain wt (g)	Grain yield (kg/ha)	Number of panicles per square meter	Number of filled spikelets / $panicle^{-1}$	Number of $grains/m^2$	Plant height (cm)	Panicle length (cm)	1000-grain wt (g)
No nitrogen (N_1)	2667	283	40	10991	86	24	22.99	3512	536	31	16877	72	20.3	23.6
Standard rate with 3 splits (N_2)	4966	404	52	21029	103	25	23.39	5275	694	34	23654	83	22.2	24.7
LCC- based N management (N_3)	4709	362	56	20228	102	25	23.31	5956	674	37	24870	85	22.9	25.4
Standard rate with 2 splits (N_4)	4565	412	49	20114	102	26	23.30	5027	761	27	20529	78	21.5	23.9
Standard rate with deep placement & LCC based (N_5)	4507	359	50	17921	99	25	23.92	5264	646	33	22259	81	21.2	24.2
CV (%)	8.8	11.9	13.8	12.4	3.4	3.1	1.3	8.9	5.5	6.3	7.4	4.1	4.0	1.3
LSD	635**	73**	8*	3781**	5.6**	1.3**	0.50**	749.1**	61.1**	3.5**	2706**	5.5**	1.5**	0.5**

a/ **= significant at 1% level, ns = not significant at 5 % level.

The highest PE_N was found in the N_3 with single-row seeding pattern, which was similar in N_5 in both seeding but significantly higher than all other N management strategies irrespective of seeding pattern (Table 3). These observations suggest prospects for improving N-use efficiency in drill-seeded rice through cultural manipulations that will lead to a more favourable crop micro-environment and higher productivity.

Table 2. Nitrogen-use efficiency as affected by N management during the wet and dry seasons.

Nitrogen management strategy	Agronomic efficiency (Δ kg grain/ kg N applied)	Recovery efficiency (Δ kg N uptake/kg N applied)	Physiological efficiency (Δ kg grain Δ kg^{-1} N uptake)	Partial factor productivity (kg grain/ kg N applied)
Wet season 2003				
No nitrogen (N_1)	-	-	-	-
Standard rate with 3 splits (N_2)	19	0.35	56	41
LCC- based N management (N_3)	22	0.37	61	51
Standard rate with 2 splits (N_4)	16	0.31	52	38
Standard rate with deep placement & LCC based (N_5)	15	0.24	65	38
CV (%)	16	19	11	7
LSD	4.9**	0.07*	7.5*	4.8**
Dry season 2004				
No nitrogen (N_1)	-	-	-	-
Standard rate with 3 splits (N_2)	12	0.34	35	44
LCC- based N management (N_3)	18	0.47	39	65
Standard rate with 2 splits (N_4)	10	0.37	27	42
Standard rate with deep placement & LCC based (N_5)	12	0.21	57	44
CV (%)	26	22	17	9
LSD	6**	0.13**	11**	7.0**

[a/] *= significant at 5% level, **= significant at 1% level.

Nitrogen balance in the soil

Nitrogen balance was estimated for the whole year (wet and dry season rice) and presented as apparent N balance and actual N balance (Table 4). The apparent N balance is the quantity of N as calculated by deducting the amount of N removed in grain and straw of the crop from the sum of the amounts of N present in soil at the beginning of wet season, applied through chemical fertilizer, and added in the soil through straw. Actual N balance refers to the NH_4^+-N and NO_3^- -N content of the soil after harvesting of dry season rice.

Ammonium N ranged from 4 to 10 kg/ha with no significant interaction between seed-drilling pattern and N management strategies. Non-significant values of NH_4^+-N before rice planting and both NH_4^+-N and NO_3^- N after rice harvest indicate no carry over of fertilizer N. The indigenous soil NO_3^- (in N_1 plot) differed with the in paired-row drill-seeded plots (N_2 and N_5) than N management strategies. The results likewise show higher in NO_3^- in paired-row seeded than the single-row seeded plots probably indicating soil heterogeneity in the experimental area which was possibly brought about by the previous experiments conducted in the same area.

Table 3. Nitrogen-use efficiency as affected by interaction effect of drill seeding pattern and management during the wet season 2003.

Drill seeding pattern	Nitrogen management strategy	Recovery efficiency (Δ kg N uptake/ kg N applied)	Physiological efficiency (Δ kg grain Δ kg^{-1} N uptake)
Single row	No nitrogen (N_1)	-	-
	Standard rate with 3 splits (N_2)	0.32	59
	LCC- based N management (N_3)	0.32	70
	Standard rate with 2 splits (N_4)	0.28	53
	Standard rate with deep placement & LCC based (N_5)	0.30	62
Paired rows	No nitrogen (N_1)	-	-
	Standard rate with 3 splits (N_2)	0.38	53
	LCC- based N management (N_3)	0.43	52
	Standard rate with 2 splits (N_4)	0.34	51
	Standard rate with deep placement & LCC based (N_5)	0.19	67
CV (%)		19	11
LSD		0.10*	11*

[a/] *= significant at 5% level, ns = not significant at 5% level.

Nitrogen in residue ranged from 8 to 18 kg/ha. Available N before planting was higher than the actual N balance indicating the mineralization of organic N during the turnaround period. Crop removal of N were statistically significant among the N management strategies within and across drill-seeding patterns, but comparisons among the four N management strategies showed that N removal was lowest in N_5. Treatment N_3 (paired-row drill seeding) had the highest crop N removed, which was statistically similar to N_4, N_3, and N_2 in single-row seeding and N_2 and N_4 in paired-row seeding. Significantly lower N removed in no N plot (N_1) in both single-row and paired-row seeded plots.

Table 4. Apparent and actual N balance as affected by different drill seeding patterns and N management strategies during the wet season 2003 and dry season 2004. [a/]

Drill seeding pattern	Nitrogen management strategy	Fertilizer applied during 2003-04 (kg/ha) (A)	N from rice straw during wet season 2003 (kg/ha) (B)	Available N in soil before wet season 2003 rice sowing (kg/ha) (C)		N removed by rice during 2003-04 (kg/ha) (D)	Available N left in soil after dry season 2004 rice harvest (kg/ha) (E)		Apparent N balance (A+B+C) -D (kg/ha)	Actual N balance (kg/ha)
				NH_4^+-N	NO_3^--N	Grain + Straw	NH_4^+-N	NO_3^- -N		
Single row	No nitrogen (N_1)	0	8	4	6	96	1	5	-78	6
	Standard rate with 3 splits (N_2)	270	16	9	5	189	5	4	111	9
	LCC- based N management (N_3)	227	13	8	7	182	3	5	73	8
	Standard rate with 2 splits (N_4)	270	15	7	10	197	3	4	105	7
	Standard rate with deep placement & LCC based (N_5)	270	16	10	10	166	7	5	140	12
Paired rows	No nitrogen (N_1)	0	7	5	5	90	3	4	-73	7
	Standard rate with 3 splits (N_2)	270	18	5	12	180	1	7	125	8
	LCC- based N management (N_3)	227	16	7	5	198	2	4	57	6
	Standard rate with 2 splits (N_4)	270	15	7	5	175	4	3	122	7
	Standard rate with deep placement & LCC based (N_5)	270	11	4	12	140	2	5	157	7
CV(%)			15	49	42	7.3	98	43		
LSD			4*	ns	6*	20*	ns	ns		

[a/] *= significant at 5% level, ns = not significant at 5% level.

Aggregate residual available N after harvest ranged from 6 to12 kg/ha, the greater bulk (60%) of which was in the NO_3^- form. Differences were not significant indicating that even the plot having no N fertilizer (N_1) had the same magnitude of available N stock for the next crop as the N-fertilized plots. Across various treatments, apparent N balance ranged from -73 to 157 kg/ha, which was remarkably higher form the actual N balance ranging 6-12 kg/ha. Although there was large amount of positive apparent N balance in N fertilized plots, these amounts were not available to the succeeding crop due to large losses resulting in a low actual N balance. Since apparent balance approach did not include the measurements of other components of N balance (N gain from biological nitrogen fixation and N loss by various mechanisms), this gave erroneous results. This is because of difficulties involved in the measurements of various gains and losses of N. Nonetheless, actual N balance allows a rough estimate of availability of residual N supply from fertilizer at the beginning of the crop and, therefore, this along with the assessment of crop N requirement for a given yield potential can be used for making fertilizer recommendation for succeeding crop.

Conclusion

Drill seeding pattern did not affect grain yield, the efficiencies of water and N use and N balance indicating that both seeding patterns had similar yield potential under dry seeding. Grain yield and N use efficiency (agronomic and recovery) were higher in the LCC-based N management (N_3) than in other strategies despite the lower N input suggesting useful uses of LCC for N management in DSR. Actual N balance across drill seeding pattern and N management during the two seasons ranged from 6-12 kg/ha, while apparent N balance ranged from 57-157 kg/ha. Although there was large amount of positive apparent N balance in N fertilized plots, these amounts were not available to the succeeding crop due to large losses resulting in a low actual N balance. A fertilizer recommendation should be based on the actual N balance along with the assessment of crop N requirement for a given yield potential for succeeding crop.

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