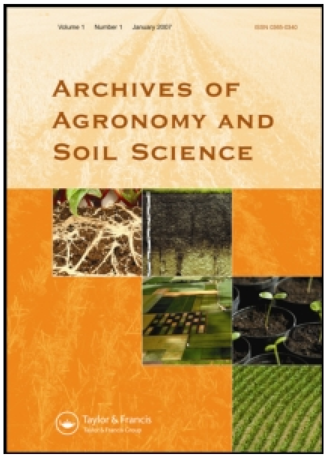

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Performance of site-specific nitrogen management for irrigated transplanted rice in northwestern India

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Abstract
Leaf colour chart (LCC) guides fertilizer nitrogen (N) application to rice as per requirement of the crop on the basis of a critical leaf colour. We evaluated need-based N management in on-farm experiments at 350 locations in the Indian Punjab during 2002 – 2005. Following LCC-based N management, from 9.4 – 54.2 kg N ha^{-1}, with an average of about 25% less fertilizer N was used, without any reduction in yield as compared to the practice of farmers of applying blanket N at fixed time intervals. Application of fertilizer N when colour of the first fully expanded leaf was less than LCC shade 4, increased nitrogen use efficiency from 48 – 65 kg grain kg N^{-1}. Nitrogen requirement of rice was site-specific both in terms of time and the amount of fertilizer N applied. In 36% of the experiments, a dose of fertilizer N was applied 55 days after transplanting (DAT) of rice. Also there were cases where only one top dressing of N was required. The study reveals that practice of applying N at fixed growth stages of rice may not be adequate and LCC-based N management can result in efficient utilisation of applied N by rice.

Keywords: *Leaf colour chart, fertilizer N management, partial factor productivity of nitrogen, rice*

Introduction

Rice is the principal cereal crop in Asia, which accounts for about 90% of the global production and consumption in rice. Irrigated rice covers 50% of the rice area and produces 75% of the total Asia's rice output (Food and Agriculture Organization [FAO] 2005). External nitrogen application is critical for intensive rice production. High grain yields can only be obtained when rice crop assimilates adequate amounts of N in the course of growing season. The N recovery by rice is generally very low and ranges from 20 – 40% depending upon source and timing of fertilizer N, crop and water management, and agro ecological conditions (Bijay-Singh & Yadvinder-Singh 2003a). The nitrogen use efficiency (NUE) varies

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with the yield potential of the variety and the growth environment (Ladha et al. 1998), but is largely determined by the extent of N loss via NH_3 volatilization, denitrification and leaching. Fertilizer N losses are estimated to range from 10 – 65% of the applied N (Cassman et al. 1998; Bijay-Singh & Yadvinder-Singh 2003b).

Fertilizer N management strategies must be responsive to temporal variations in crop N demands and soil N supply in order to achieve supply-demand synchrony and to minimise N losses. Proper timings of N application have been shown to be crucial to minimise N losses and to increase crop N recovery (Becker et al. 1994). Improving the synchrony between crop N demand and the N supply from soil and/or the applied N fertilizer is likely to be the most promising strategy to increase NUE in rice. Current fertilizer recommendations for rice in most rice growing countries of Asia typically consist of fixed rate and timing on a regional scale. In northwestern India, blanket recommendation is to apply 120 kg N ha^{-1} at 0, 21 and 42 days after transplanting (DAT). Due to enormous farm-to-farm variability in soil nutrient N supply, blanket recommendations for fertilizer N application for a large region generally lead to low NUE. To avoid the risk of N deficiency, many a time farmers apply fertilizer N in excess, which also leads to low N recovery by rice.

Real-time N management strategies aim at meeting fertilizer N supply with actual crop demand to maximize crop N uptake and reduce N losses to environment (Bijay-Singh et al. 2002; Balasubramanian et al. 2003; Shukla et al. 2004). The potential solution to manage N applications to rice comprises of use of chlorophyll meter or leaf colour chart to guide fertilizer application. The chlorophyll meter is a quick, reliable, and non-destructive tool for designing the N status of crop and thus for determining the right time of N top dressing (Peng et al. 1995; Bijay-Singh et al. 2002; Shukla et al. 2004). However, the high cost of a chlorophyll meter restricts its widespread use by the farmers. Scientists at the International Rice Research Institute (IRRI) introduced a leaf colour chart (IRRI 1996), an inexpensive and simple diagnostic tool to monitor need-based N applications to rice. It is a successful substitute for a chlorophyll meter as it also works on the basic principal that rice leaf colour is a good indicator of leaf N content (Bijay-Singh et al. 2002).

Farmers can use the leaf colour chart (LCC) as a visual and subjective indicator of the rice crop's N status and thus the need for N fertilizer application. The LCC has been successfully tested for N management in rice (Bijay-Singh et al. 2002; Balasubramanian et al. 2003; Shukla et al. 2004; Alam et al. 2005; Yadvinder-Singh et al. 2007). Large-scale testing of the suitability of LCC-based N management strategies in rice is required in different agro-climatic regions to achieve recommendable decisions. The current four-year study was carried out with the objective of evaluating grain yield and N use differences in the field-specific N fertilizer management based on LCC, and the practice of farmers of applying fertilizer N at fixed-time intervals to irrigated rice in different regions of northwestern India.

Materials and methods

A total of 350 on-farm experiments were conducted during 2002 – 2005 in 10 districts of the Indian Punjab to evaluate LCC-based N management in rice, vis-à-vis the farmers' practice of applying N at fixed growth stages of rice. The districts were selected to cover major agro-climatic regions of northwestern India. District Gurdaspur and Ropar represents sub-humid region with an annual rainfall of 800 – 900 mm and mean annual soil temperature of 22°C. Soil pH varies from 6.7 – 8.5, EC is less than 0.2 dS m^{-1} and organic carbon varies from 2 – 9 g kg^{-1} soil. The water table is shallow and soils are fine textured traditionally rice soils. A semi-arid region with annual rainfall of 400 – 800 mm and mean annual soil temperature 24°C is represented by the districts Amritsar, Kapurthala, Jalandhar, Ludhiana and Patiala.

The soil pH ranges from 7.6–8.7, EC is less than 0.54 dS m^{-1} and organic carbon in the surface layer ranges from 1–7 g kg^{-1} soil. Soils are coarse textured and non traditional rice soils. The districts Bhatinda, Sangrur and Ferozpur cover an arid region of the state with annual rain fall of about 400 mm and mean annual soil temperature of 25–26°C. Soil pH ranges from 8.0–9.5; EC is less than 1.2 dS m^{-1} and organic carbon in the surface layer varies from 2–7.5 g kg^{-1} soil. The water table is deep and soils are well drained, coarse textured non traditional rice sols. Farmers were selected randomly by the scientific staff and preference was given to educated and willing farmers who could understand the philosophy of need-based N management and could use the leaf colour chart. The experiments were conducted with the cooperation and help of farmers under the direct supervision of the scientific staff.

During the first year (2002), experiments were conducted at fields of 107 farmers in the Patiala, Amritsar, Bhatinda, Sangrur, Kapurthala and Jalandhar districts. During the second year (2003), 48 sites were selected in Amritsar, Ferozpur, Patiala, Gurdaspur, Jalandhar and Ropar districts. The need-based N management technology was evaluated at 53 locations in 2004 and 142 locations in 2005 covering different blocks of Ludhiana district. The soils of the experimental fields were loamy sand to sandy loam in texture, having pH 7.0–8.5, electrical conductivity 0.1–0.5 dS m^{-1} and 2–9 g organic carbon per kg soil. The soils tested medium to high in Olsen available P and low to medium in ammonium acetate extractable available K content. Based upon the results of the detailed experimentation on need-based N management in rice using LCC (Bijay-Singh et al. 2002), shade 4 on the LCC was used as the critical value for guiding fertilizer N application to rice. In the LCC-based N management, a basal dose of 30 kg N ha^{-1} was applied at the time of last puddling followed by need-based N applications using LCC. The practice of farmers (fixed-time N application schedule) of applying N in 3 split doses at transplanting, 3 weeks and 6 weeks after transplanting of rice, was compared with the LCC-based N management practice.

Leaf colour chart measurements and fertilizer N application

The LCC developed by the International Rice Research Institute (IRRI 1996) with strips of six shades of green colour showing increasing intensity of colour with increasing number was used in the study. Ten disease-free rice plants were randomly selected from the each plot. The topmost fully expanded leaf was placed on the top of the leaf colour chart and the colour of the middle part of the leaf was graded according to the corresponding colour strip on the LCC. During measurement, the leaf being measured was kept under the shade of the body to avoid the colour variance caused by sunlight. The LCC readings were taken at weekly intervals starting from 15 days after transplanting of rice until initiation of the flowering stage, preferably by the same person at the same time of the day. When the colours of 6 out of 10 leaves fell below a threshold of shade four on the LCC, 30 kg N ha^{-1} was top dressed on the same day. Date of N application in need-based N application treatment was also recorded in 50 on-farm experiments during 2004.

Crop management

The preceding crop at all the on-farm locations was wheat and farmers generally apply 120–150 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} to wheat. After the harvesting of wheat, the land was ploughed, puddled and leveled for rice transplanting in June. Experiments were conducted in 4000 m^2 plots. The plots were divided in two equal halves to compare LCC-based and the farmers' N management practices. Two 4- to 5-week-old rice seedlings were randomly transplanted at the rate of 22 – 25 hills m^2 in all the farmers' fields. Nitrogen was applied as urea $[(NH_2)_2\ CO]$ containing 46% N. No P and K applications were made to rice as per Punjab Agricultural University recommendations (Punjab Agricultural University 2002). Basal application of 25 kg $ZnSO_4$ ha^{-1} was made at the time of the last puddling. Irrigation was provided using both canal and well waters. Nitrate content in the irrigation water (canal or well) varied from 2 – 5 mg l^{-1}. Well water contains slightly higher N than canal water. The same source of irrigation was used for LCC-managed and farmers' N-managed plots at all the locations. Plots were kept flooded for the first two weeks after transplanting; thereafter, rice was irrigated two days after the infiltration of irrigation water. Experiments were conducted irrespective of the cultivars, and the same N management practice was used for need-based N application for different cultivars. The crop was harvested by hand at ground level at maturity in the month October and grain yields were recorded from a 100 m^2 area in the center of each plot.

Data analysis

Randomised block design was used to determine the effect of method of N application on yield and nitrogen requirement of rice crop. Partial factor productivity (PFP_N) of applied N was calculated as a measure of nitrogen use efficiency:

$$PFP_N = Y_N/F_N$$

It is of importance for farmers as it integrates the use efficiency of both indigenous and applied N sources (Dobermann 2005):

$$PFP_N = (Y_0/F_N) + AE_N$$

where Y_0 = crop yield in control treatment with no N; Y_N = crop yield with applied nitrogen; F_N = amount of fertilizer N applied kg ha^{-1}; and $AE_N = (Y_N - Y_0/F_N)$; agronomic efficiency of applied N as kg yield increase per kg of applied nitrogen.

The percentage N saving with the LCC-based N application over fixed time farmers' practice was calculated to differentiate N requirement of the crop with different N management practices.

Results and discussion

Rice grain yield

Grain yield of rice in 350 on-farm experiments conducted during 2002 – 2005, all over the region varied from 4 – 9 t ha^{-1} in fixed time N application (farmers' practice) treatment and 4.1 – 9.5 t ha^{-1} in LCC-based real-time N management treatment (Tables I – IV). Although average yield from the two treatments across years and regions were similar, a large field-to-field and season-to-season variation in the grain yield of rice was observed. For example, mean yields from LCC-based N management during 2002 – 2005 were 6.0, 6.5, 8.2 and 7.1 t ha^{-1}, respectively. Corresponding rice yields with N management following the farmers' practice were 6.0, 6.5, 8.1 and 7.0 t ha^{-1}, respectively. These yield trends suggest that performance of LCC-based real-time N management, i.e. fixed time N schedule as followed by farmers, is not influenced by season. Similar results have been reported in the earlier studies conducted in the Indo-Gangetic plains of India (Bijay-Singh et al. 2002;

Table I. Effect of N management practices on N application and grain yield of rice in 2002 in northwestern India.

Blocks	No. of farmers		Rice grain yield (t ha^{-1}) LCC	FP	LSD (0.05)	Fertilizer applied (kg N ha^{-1}) LCC	FP	LSD (0.05)	Percentage N saving	PFP (kg grain kg^{-1} N) LCC	FP
Patiala	39	Range	4.6 – 7.1	4.6 – 7.1		98 – 109	127 – 190				
		Mean	6.0	6.1	NS	99.8	158.1	5.82	36.8	60.5	38.3
Amritsar	50	Range	4.1 – 7.7	4.0 – 7.4		86 – 144	86 – 219				
		Mean	6.1	6.0	NS	122.8	154.1	6.02	20.3	49.8	39.0
Bhatinda	4	Range	4.7 – 6.4	5.1 – 6.5		58 – 132	81 – 132				
		Mean	5.6	5.6	NS	107.0	116.4	NS	8.1	52.2	48.4
Sangrur	4	Range	6.3 – 7.0	6.5 – 7.5		98 – 144	138 – 144				
		Mean	6.5	6.9	0.187	115.0	153.8	13.8	25.2	56.6	44.9
Kapurthala	5	Range	5.0 – 6.6	4.6 – 6.1		109 – 132	127 – 150				
		Mean	5.2	5.2	NS	113.9	135.7	12.8	16.1	45.6	38.0
Jalandhar	5	Range	4.6 – 6.4	4.8 – 6.2		92 – 121	127 – 173				
		Mean	5.5	5.5	NS	115.0	140.3	24.5	18.0	47.7	39.1
Mean	107		6.0	6.0	NS	112.8	152.6	4.87	21.6	53.2	39.3

LCC, Leaf colour chart-based N management practice; FP, Farmers' practice.

Table II. Effect of N management practices on N application and grain yield of rice in 2003 in northwestern India.

District	No. of farmers		Rice grain yield ($t\ ha^{-1}$)			Fertilizer applied ($kg\ N\ ha^{-1}$)			Percent-age N saving	PFP (kg grain kg^{-1} N)	
			LCC	FP	LSD (0.05)	LCC	FP	LSD (0.05)		LCC	FP
Amritsar	4	Range	4.9–6.1	4.9–6.1		100–125	100–150				
		Mean	5.6	5.6	NS	106.3	117.5	NS	9.6	52.6	47.5
Ferozpur	6	Range	6.7–7.0	6.4–6.9		100	110				
		Mean	6.9	6.7	0.063	100	110	0.0001	9.1	68.5	60.5
Patiala	4	Range	8.6–9.0	8.3–8.9		80	110–125				
		Mean	8.7	8.6	NS	80	118.8	10.0	32.6	109.1	72.1
Gurdaspur	18	Range	6.1–6.8	6.2–6.8		80–130	110–140				
		Mean	6.4	6.4	NS	96.6	121.1	4.5	20.2	66.1	52.8
Jallandhar	5	Range	6.1–7.0	6.3–7.1		75–100	100–130				
		Mean	6.5	6.6	0.08	85	114.0	8.0	25.4	76.1	57.9
Ropar	11	Range	5.7–6.4	5.8–6.4		75–90	90–125				
		Mean	6.1	6.1	NS	79.5	105.9	6.9	24.9	77.0	58.0
Mean	48		6.5 NS	6.5	NS	91.4	115	3.27	20.5	71.1	56.5

LCC, Leaf colour chart-based N management practice; FP, Farmers' practice.

Table III. Effect of N management practices on N application and grain yield of rice in 2004 in northwestern India.

Blocks	No. of farmers		Rice grain yield (t ha^{-1}) LCC	FP	LSD (0.05)	Fertilizer applied (kg N ha^{-1}) LCC	FP	LSD (0.05)	Per cent N saving	PFP (kg grain kg^{-1} N) LCC	FP
Ludhiana	10	Range	7.5–8.3	7.6–8.3		81	127–138				
		Mean	7.8	7.9	NS	81	132.3	3.9	39.1	96.9	59.7
Khanna	10	Range	7.5–8.4	7.5–8.3		86	127–138				
		Mean	8.0	8.0	NS	86	130.0	4.0	33.6	92.8	61.6
Pakhowal	5	Range	8.3–8.8	7.7–8.6		58–115	115–144				
		Mean	8.5	8.3	NS	86.3	120.8	15.9	28.6	98.6	68.7
Sudhar	7	Range	6.2–9.9	6.1–9		86–104	115–144				
		Mean	7.9	7.7	NS	89.5	133.9	9.1	33.2	88.3	57.5
Dehlon	10	Range	8.0–9.1	7.9–9		115–144	127–144				
		Mean	8.5	8.4	NS	127	139.7	11.3	9.1	66.9	60.1
Jagraon	11	Range	8.1–9	8–8.9		115–144	127–155				
		Mean	8.6	8.4	0.07	117.6	138.5	4.9	15.1	73.0	60.9
Mean	53		8.2	8.1	NS	99.8	133.7	4.53	25.4	82.2	60.6

LCC, Leaf colour chart-based N management practice; FP, Farmers' practice.

Table IV. Effect of N management practices on N requirement and grain yield of rice in 2005 in northwestern India.

Blocks	No. of farmers		Rice grain yield (t ha^{-1}) LCC	Rice grain yield (t ha^{-1}) FP	Rice grain yield (t ha^{-1}) LSD (0.05)	Fertilizer applied (kg N ha^{-1}) LCC	Fertilizer applied (kg N ha^{-1}) FP	Fertilizer applied (kg N ha^{-1}) LSD (0.05)	Percent N saving	PFP (kg grain kg^{-1} N) LCC	PFP (kg grain kg^{-1} N) FP
Dehlon	50	Range	6.6–8.3	6.6–8.8		104–144	127–150				
		Mean	7.8	7.7	0.06	120.5	141.3	2.5	14.7	64.7	54.8
Samrala	20	Range	5.8–7.5	5.8–7.3		115	127–173				
		Mean	6.6	6.5	NS	115	156	7.1	26.3	57.4	41.6
Mangat	22	Range	6.2–9.5	5.9–7.1		86–144	115–173				
		Mean	6.8	6.6	NS	117.6	152.9	8.9	23.1	57.8	43.2
Sudhar	50	Range	5.9–7.3	6–7.1		69–98	127–161				
		Mean	6.5	6.5	NS	86.3	140.5	2.5	38.6	75.7	46.3
Mean	142		7.1	7.0	0.06	107.2	144.9	4.0	26.0	66.2	48.3

LCC, Leaf colour chart-based N management practice; FP, Farmers' practice.

Yadvinder-Singh et al. 2006) and elsewhere in Asia (Alam et al. 2005, 2006). Grain yield in most of the experiments was on a par in both the N management practices. Nevertheless a significant increase in rice grain yield was observed in the Ferozepur district in 2003, Jagraon block of Ludhiana district in 2004 and Dehlon block of Ludhiana district in 2005. Yield reduction was also observed with LCC-based N management practice in Sangrur district in 2002 and Jalandhar district in 2003, but, partial factor productivity (PFP_N) increased from 44.9 kg grain kg N^{-1} to 56.6 kg grain kg N^{-1} in Sangrur and from 57.9 kg grain kg N^{-1} to 76.1 kg grain kg N^{-1} in Jalandhar.

Fertilizer N application

During 2002, the amount of N fertilizer applied in the LCC-based N management treatment ranged from 58–144 kg N ha^{-1} (mean 113 kg N ha^{-1}). The amount of N applied in farmers' practice ranged from 81–219 kg ha^{-1} with a mean value of 153 kg N ha^{-1} (Table I). Based on the results from 107 on-farm experiments, the total N applied was 35.2% higher under the farmers' practice than in the LCC-based real-time N management treatment. The difference in N fertilizer applied between the two N management treatments was, however, not statistically significant in Bhatinda district. In 2003, the amount on N fertilizer applied in the LCC-based N management treatment ranged from 75–130 kg N ha^{-1} (mean 91 kg N ha^{-1}); the range was from 100–150 kg N ha^{-1} (mean 115 kg N ha^{-1}) in the case of the farmers' practice (Table II). Total N applied in 48 experiments conducted during 2003 was 25.8% higher in the farmers' practice of applying N at fixed time interval than in the LCC-based need-based N management treatment (Table II). The differences in N applied in the two treatments were, however, not significant in Amritsar district, where 4 out of a total 48 experiments were conducted during 2003. Similarly, the total amount of N applied to rice during 2004 in LCC-based N management treatment ranged from 58–144 kg N ha^{-1} (mean 100 kg N ha^{-1}) and the amount of N applied ranged from 115–155 kg N ha^{-1} (mean of 134 kg N ha^{-1}) in the farmers' practice (Table III). Based on the results from 53 on-farm trials in Ludhiana district, the total N fertilizer applied was 33.9% higher under the farmers' practice than in the LCC-based real-time N management treatment. In Ludhiana district, at one of the sites at Pakhowal block N management with the LCC-based technology can save N even up to 50%. The amount of fertilizer N applied in this experiment was as low as 57.5 kg N ha^{-1} and it produced a grain yield equivalent to that with fixed-time N application of 115 kg N ha^{-1}.

In 2005, the amount of N fertilizer applied in the LCC-based N management treatment ranged from 69–144 kg N ha^{-1} (mean 107 kg N ha^{-1}); it ranged from 115–173 kg N ha^{-1} (mean 145 kg N ha^{-1}) for the farmers' practice (Table IV). On an average, total N fertilizer applied was 35.2% higher under farmers' practice than in the LCC-based real-time N management treatment. Data from four years of experimentation at 350 on-farm sites in northwestern India indicate that average yield recorded in the LCC-based real-time N management and that obtained in fixed-time N application as followed by the farmers were identical (Figure 1), but on average, need-based fertilizer N management require about 36 kg ha^{-1} less fertilizer N as compared to farmers' practice.

Data recorded in Tables I–IV emphatically suggests that farmers generally apply nitrogen fertilizers in excess of crop requirement of the crop. But it does not mean that LCC-based N application will always result in the application of less fertilizer N than the farmers' practice. At some locations, farmers were applying N fertilizers less than the crop need. At these locations, use of LCC for guiding fertilizer N application to rice should result in N application more than the farmers' practice, but it would improve yield as fertilizer N will be applied as per need of the crop. High field-to-field and year-to-year variation in N-supplying capacity of

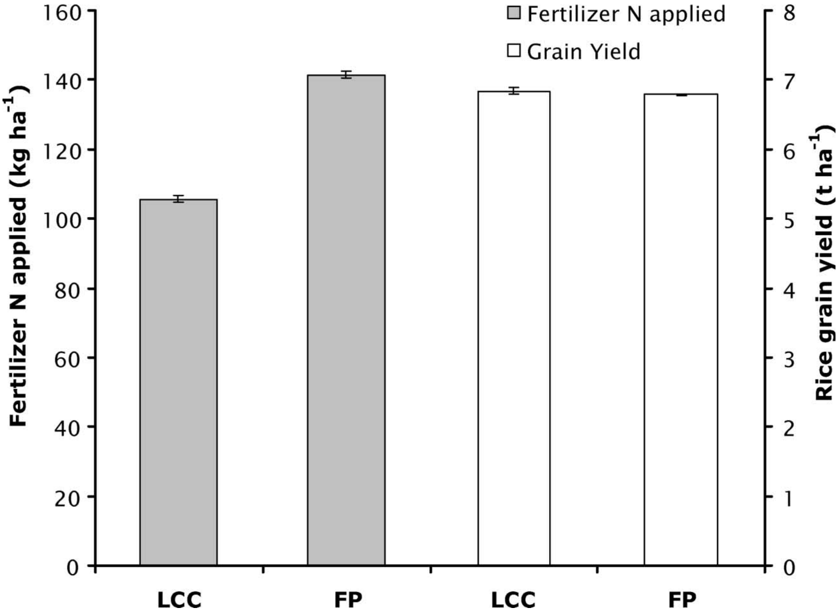

Figure 1. Average fertilizer N applied and grain yield of rice in 350 on-farm trials comparing LCC-based N management (LCC) with farmers' practice (FP) in Indian Punjab.

soils and thus fertilizer N requirement of rice was observed in many soils (Cassman et al. 1996; Dobermann et al. 2003). Results from this study and earlier studies by Alam et al. (2005; 2006), Bijay-Singh et al. (2002) and Yadvinder-Singh et al. (2006) suggest that the current recommendation of fixed-time three split applications at specified growth stages does not lead to adequate synchronisation of N supply with actual crop N demand.

Partial factor productivity

The superiority of LCC-based N management in increasing synchrony of N applications with crop needs and improving N use efficiency over farmers' practice (N application at fixed time intervals) was revealed from higher PFP_N during different years. Need-based fertilizer N application in 2002 resulted in partial factor productivity (PFP_N) of 58.4 kg grain per kg of applied N, i.e. 39.3 kg grain per kg N observed for fixed time N application. Increase in PFP_N was observed in 2003, 2004 and 2005 as well. LCC-based N management resulted in 14.6, 21.6 and 17.9 kg grain per kg applied N higher PFP_N than those observed by following farmers' N management during 2003, 2004 and 2005, respectively. Data from four-year experimentation in farmers' fields at 350 locations showed that real-time N application technology increased partial factor productivity from 48.0–64.7 kg grain per kg applied N in rice. High PFP_N values associated with real-time N management suggest that farmers have a tendency to apply fertilizer N more than the need of the crops to produce adequate yield levels. Applying N at three fixed growth stages of the rice possibly leads to more loss of nitrogen and thus low PFP_N. Data pertaining to PFP_N when plotted against grain yield (Figure 2) further reveals that although PFP_N increases with increasing grain yield under both N management options at any given grain yield level, LCC-based N management leads to a considerably higher PFP_N than that observed under

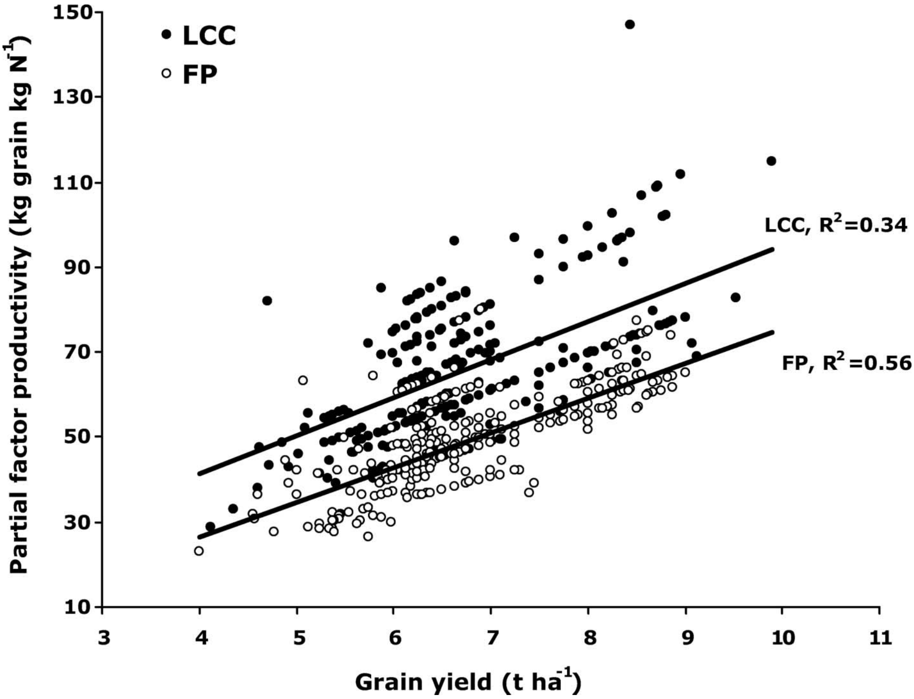

Figure 2. Relationships between partial factor productivity and grain yield of rice for leaf colour chart (LCC) based N management and farmers' practice (FP) of a blanket fertilizer dose in 350 on-farm experiments conducted throughout the Punjab in northwestern India.

the practice of farmers. Exceptionally high PFP_N value and a greater degree of scatter in values observed for need-based N management indicate that grain yield was not only governed by applied fertilizer N but soil N supply to rice was also adequately taken care of due to application of fertilizer N at the right time and in the right quantity. On the other hand, under the farmers' practice, yields were more defined by high fertilizer N supply; these were better correlated with PFP_N value than under LCC-based N management. And high N application levels following the practice of farmers resulted in substantial losses, as applied N did not adequately synchronise with plant N need, and thus leads to low PFP_N.

Fertilizer N application schedule in need based N management

High N use efficiency with need-based N application was obtained because N was applied when it was needed by the crop. The amount of total N applied at a particular location was a function of the number of times the fertilizer N was applied during the crop season. Scheduling of fertilizer N is the core element in the LCC-based need-based N management. A critical analysis of the fixed N schedule of 50 experiments conducted during 2004 is presented in Table V. The first top dressing of N fertilizer was applied within 20 days of transplanting of rice at 44% of the experimental sites; it was applied during 21 – 40 DAT at 54% locations. The second dose of fertilizer N as guided by LCC was top dressed during 21 – 40 and 41 – 55 DAT at 48% and 41% of the experimental sites. The third top dressing of

Table V. Schedule of fertilizer N application in LCC-based N application treatment in 50 on-farm trials at farmers' fields during 2004 in northwestern India.

Days after transplanting	Number of farmers		
	1st dose*	2nd dose*	3rd dose*
<20	22	2	–
21–40	27	21	3
41–55	1	18	8
>55	–	4	14
Total	50	43	25

*After basal dose of 30 kg N ha^{-1}.

fertilizer N was required in 50% of the locations, and out of these, at 56% of locations it was applied after 55 days of transplanting. These data emphatically suggest that fertilizer N applications made even 55 days after transplanting of rice can be efficiently utilised by rice, if N supply is inadequate from soil or from previous applications.

The notion that the first top dressing should be given at 21 DAT and no fertilizer N should be applied to rice 42 DAT will hold good, only if 120 kg N ha^{-1} or more fertilizer N is applied to rice, as only then it leads to rice yield similar to that obtained by need-based N applications, which are generally less than the blanket recommendation. The competence of LCC-based N management to take care of the field-to-field variations is reflected in the fact that at 50% locations, 3 doses of N were applied after a basal dose, whereas at 36% and 14% of locations only 2 and 1 top dressings of N were required respectively, to obtain yields comparable to those obtained by following the practice of farmers. The N applications made on the basis of shade 4 on the LCC as critical leaf colour seem to take care of N supply from all applied (irrigation water, organic, bio-, or chemical fertilizers) as well as inherent soil N resources.

Conclusions

Need-based application of fertilizer N to irrigated transplanted rice in northwestern India following shade 4 on the LCC as the critical leaf colour produces as much grain yield of rice as produced by applying 120 kg N ha^{-1} or more fertilizer N in three equal splits at transplanting and 3 and 6 weeks after transplanting. The practice by farmers to take care of field-to-field and temporal variations in soil N supply caused a substantially higher amount of fertilizer N to be applied. In contrast, real-time need-based fertilizer N management synchronized well with the N requirements of the rice crop thereby resulting in substantially higher partial factor productivity. Leaf colour chart-based N management could adequately take care of field-to-field and temporal variation in N supply to rice and thus holds promise in increasing fertilizer N use efficiency in rice.

References

Alam MM, Ladha JK, Foyjunnessa, Rahman Z, Khan SR, Rashid H, Khan AH, Buresh RJ. 2006. Nutrient management for increased productivity of rice-wheat cropping system in Bangladesh. Field Crops Res 96:374–386.

Alam MM, Ladha JK, Khan SR, Foyjunnessa, Rashid H, Khan AH, Buresh RJ. 2005. Leaf color chart for managing nitrogen fertilizer in lowland rice in Bangladesh. Agron J 97:949–959.

Balasubramanian V, Ladha JK, Gupta RK, Naresh RK, Mehla RS, Bijay-Singh, Yadvinder-Singh. 2003. Technology options for rice in the rice-wheat system in South Asia. In: Ladha JK, Hill JE, Duxbury JM, Gupta RK, Buresh RJ, editors. Improving the productivity and sustainability of rice-wheat systems: Issues and impact. ASA Special Publication No. 65. Madison, WI: ASA, CSSA & SSSA. pp 115 – 147.

Becker M, Ladha JK, Ottow JCG. 1994. Nitrogen losses and lowland rice yield as affected by residue N release. Soil Sci Soc Am J 58:1660 – 1665.

Bijay-Singh, Yadvinder-Singh. 2003a. Nitrogen management in rice-wheat system in the Indo-gangetic plains. In: Yadvinder-Singh, Bijay-Singh, Nayyar VK, Singh J, editors. Nutrient management for sustainable rice-wheat cropping system. National Agricultural Technology Project, Indian Council of Agricultural Research, New Delhi, India, and Punjab Agricultural University, Ludhiana, Punjab, India. pp 99 – 114.

Bijay-Singh, Yadvinder-Singh. 2003b. Gaseous losses of nitrogen from soils under rice-wheat system. In: Yadvinder-Singh, Bijay-Singh, Nayyar VK, Singh J, editors. Nutrient management for sustainable rice-wheat cropping system. National Agricultural Technology Project, Indian Council of Agricultural Research, New Delhi, India, and Punjab Agricultural University, Ludhiana, Punjab, India. pp 125 – 144.

Bijay-Singh, Yadvinder-Singh, Ladha JK, Bronson KF, Balasubramanian V, Singh J, Khind CS. 2002. Chlorophyll meter- and leaf color chart-based nitrogen management for rice and wheat in northeastern India. Agron J 94:821 – 829.

Cassman KG, Gines GC, Dizon MA, Samson MI, Alcantara JM. 1996. Nitrogen-use efficiency in tropical lowland rice systems: Contributions from indigenous and applied nitrogen. Field Crops Res 47:1 – 12.

Cassman KG, Peng S, Olk DC, Ladha JK, Reichardt W, Dobermann A, Singh U. 1998. Opportunities for increased nitrogen use efficiency from improved resource management in irrigated rice systems. Field Crops Res 56:7 – 38.

Dobermann A. 2005. Nitrogen use efficiency – state of art. IFA International workshop on enhanced-efficiency fertilizers Frakfurt, Germany, 28 – 30 June 2005.

Dobermann A, Witt C, Abdulrachman S, Gines HC, Nagarajan R, Son TT, Tan PS, Wang GH, Chien NV, Thoa TK, Phung CV, Stalin P, Muthukrishnan P, Ravi V, Babu M, Simbahan GC, Adviento MAA. 2003. Soil fertility and indigenous nutrient supply in irrigated rice domains of Asia. Agron J 95:913 – 923.

Food and Agriculture Organization (FAO). 2005. FAOSTAT Agricultural Data base, Food and Agriculture Organization, Rome (available at http://faostat.fao.org/faostat/servlet/).

International Rice Research Institute (IRRI). 1996. Use of leaf colour chart (LCC) for N management in rice. Crop Resour Manage Network Technol. Brief 2. IRRI, Manila, Philipines.

Ladha JK, Kirk GJD, Bennett J, Peng S, Reddy CK, Reddy PM, Singh U. 1998. Opportunities for increased nitrogen-use efficiency from improved lowland rice germplasm. Field Crops Res 56:41 – 71.

Peng S, Garcia FV, Laza RC, Cassman KG. 1995. Chlorophyll meter estimates leaf area based leaf area based nitrogen concentration of rice. Commun Soil Sci Plant Anal 26:927 – 935.

Punjab Agricultural University. 2002. Package of practices for crops of Punjab, Punjab Agricultural University, Ludhiana, India.

Shukla AK, Ladha JK, Singh VK, Dwivedi BS, Balasubramanian V, Gupta RJ, Sharma SK, Singh Y, Pathak H, Pandey PS, Padre AT, Yadav RL. 2004. Calibrating the leaf color chart for nitrogen management in different genotypes of rice and wheat in a systems perspective. Agron J 96:1606 – 1621.

Yadvinder-Singh, Bains JS, Bijay-Singh. 2006. Need based fertilizer nitrogen management using leaf colour chart in irrigated rice in Punjab, India. Proceedings International Crop Science Congress, Brisbane, Australia. Accessed at: www.cropscience.org.au/icsc2004/poster/2/5/1/649_singhy.htm

Yadvinder-Singh, Bijay-Singh, Ladha JK, Bains JS, Gupta RK, Jagmohan-Singh, Balasubramanian V. 2007. On-farm evaluation of leaf color chart for need-based nitrogen management in irrigated transplanted rice in northwestern India. Nutr Cycling Agroecosyst 78:167 – 176.