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Fixed-time adjustable dose site-specific fertilizer nitrogen management in transplanted irrigated rice (*Oryza sativa* L.) in South Asia

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ABSTRACT

In the quest of enhancing nitrogen (N) use efficiency in irrigated transplanted rice beyond that observed with blanket recommendation, leaf colour chart (LCC) is being used to apply N whenever colour of the first fully opened leaf from the top is less green than a critical colour shade. So as to avoid frequent (every 7–10 days) monitoring of leaf colour, criteria were developed to apply fertilizer N at critical growth stages of rice but by adjusting the dose of N as per colour of the leaf measured with LCC. A series of experiments were carried out at Ludhiana and Gurdaspur locations from 2007 to 2010 with treatments refined progressively to work out appropriate combination of fixed and adjustable rates of fertilizer N at critical stages of transplanted rice. A dose of 30 kg N ha^{-1} at transplanting as prescriptive N management proved to be adequate for achieving high yields of rice. Corrective N management consisting of adjustable N doses was worked out as application of 45, 30 or 0 kg N ha^{-1} depending upon leaf colour to be <LCC shade 4, between LCC shade 4 and 5 or ≥LCC shade 5 both at maximum tillering and panicle initiation stages, and 30 kg N ha^{-1} only if leaf colour is less green than LCC shade 4 at initiation of flowering. A combination of these prescriptive and corrective N management strategies resulted in optimum rice grain yield and high N use efficiency with less fertilizer N application than the blanket recommendation. For some rice cultivars, particularly in years with favorable climate, fixed date adjustable dose N management produced yield levels higher than those achieved by applying blanket recommendation for fertilizer N and resulted in agronomic efficiency higher than 25 kg grain/kg N.

1. Introduction

Current fertilizer nitrogen (N) recommendations for irrigated rice (*Oryza sativa* L.) typically consist of fixed rates and timings for large rice growing tracts having similar climate and landforms. These blanket recommendations have served the purpose well but cannot help increase N use efficiency beyond a limit. Due to large field-to-field variability of soil N supply, efficient use of N fertilizer is not possible when broad-based blanket recommendations for fertilizer N are used (Adhikari et al., 1999). The blanket recommendations are also not responsive to temporal variations in crop N demands.

The main reason of low N use efficiency is inefficient splitting of N applications, including the use of N in excess to the requirements. Since 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 N use efficiency, the split application of fertilizer N is going to remain an essential component of fertilizer N management strategies in rice. Recent advances in N management for rice include adjustment of the early N application to match the relatively low demand of young rice plants and varying rates and distribution of fertilizer N within the growing season to match crop demand for supplemental N. In this respect, the leaf N status of rice, which is closely related to photosynthetic rate and biomass production, serves as a sensitive indicator of the crop demand for N during the growing season (Buresh, 2007). As rice leaf colour is a good indicator of leaf N content, the leaf colour chart (LCC) developed through collaboration of the International Rice Research Institute (IRRI) with agricultural research systems of several countries in Asia (IRRI, 1996) serves as a visual and subjective indicator of plant N deficiency. With its six colour panels of different shades of green, LCC is used as a reference tool for evaluating colour of the leaves and it is becoming popular as an inexpensive and easy-to-use tool for estimating leaf N content and managing fertilizer N in rice. Although in 2004 IRRI introduced a new version of LCC with more sophisticated matching of panel colours to leaf colours (Witt et al., 2005), the older version of the LCC is being manufactured and extensively used in India and works well for

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Table 1
Some characteristics of the surface soil (0–15 cm) of the experimental fields.

	Ludhiana					Gurdaspur		
	2007	2008	2009	2010-A	2010-B	2007	2008	2009
pH[a]	7.0	6.9	7.0	7.1	7.1	6.9	6.9	6.9
Electrical conductivity[a]	0.17	0.18	0.16	0.21	0.23	0.21	0.20	0.21
Organic C (%)[b]	0.42	0.41	0.38	0.44	0.42	0.50	0.54	0.51
Sand (g kg^{-1})	725	725	802	794	810	415	470	415
Clay (g kg^{-1})	96	96	92	85	83	110	145	110
Silt (g kg^{-1})	175	175	106	121	107	475	385	475
NO_3^- + NH_4^+ – N at transplanting (mg kg^{-1})[c]	7.8	9.2	6.6	5.2	5.9	12.2	14.1	11.8
Total N (g kg^{-1})[d]	0.56	0.57	0.61	0.65	0.64	0.78	0.82	0.76

[a] 1:2 soil/water.
[b] Walkley (1947).
[c] Bremner (1965b).
[d] Bremner (1965a).

managing fertilizer N in rice, wheat and maize (Bijay-Singh et al., 2002; Bijay-Singh, 2008; Varinderpal-Singh et al., 2010, 2011).

Guidelines initially established with LCC were based on real time N management in which leaf colour was monitored at 7- to 10-day intervals during the growing season. Fertilizer N was applied whenever the leaves were less greenish than a threshold LCC value, which corresponds to a critical leaf N content (Balasubramanian et al., 1999; Bijay-Singh et al., 2002; Varinderpal-Singh et al., 2007; Yadvinder-Singh et al., 2007). Many a times, farmers prefer less frequent monitoring of leaf colour as they are strongly accustomed to apply fertilizer N at growth stages as per blanket recommendation. An alternative fixed-time option involves monitoring of leaf colour only at active tillering around 21 days after transplanting (DAT), at panicle initiation around 42 DAT and a week before initiation of flowering. These are the growth stages critical for a sufficient supply of N. Applications of fertilizer N upward or downward can then be adjusted based on leaf colour, which reflects the relative need of the crop for N at these stages. Witt et al. (2007) has described the fixed-time adjustable dose strategy in which split N application doses at active tillering and panicle initiation of transplanted rice are given based on expected yield response and leaf colour defined by IRRI–LCC as yellowish green (LCC value 3), intermediate (LCC value 3.5) and green (LCC value 4). Peng et al. (2006, 2007), Dobermann et al. (2002), and Wang et al. (2007) have evaluated a number of variants of the fixed-time adjustable dose strategy by using different critical SPAD/IRRI LCC values and percentage of fertilizer N to be applied at different critical growth stages. These studies however, do not provide guidelines simple enough to be adoptable by South Asian farmers. Also these strategies are not compatible with LCC being used in India. We, therefore, conducted a series of field experiments to work out a criteria based on leaf colour to apply fertilizer N as per crop demand at critical growth stages for transplanted rice in South Asia. The new version of LCC promoted by IRRI (Witt et al., 2005) was not used in this study because the LCC manufactured by Nitrogen Parameters, Chennai, India is readily available in South Asia and is already in possession of a large number of farmers.

2. Materials and methods

The field experiments were conducted at two sites for 4 years (2007–2010): at Ludhiana (30.91°N, 75.85°E) on a Typic Ustipsamment (Fatehpur sandy loam) in the Research Farm of the Punjab Agricultural University, and at Gurdaspur (32.03°N, 75.40°E) on a Typic Haplustalf (Gurdaspur loam) in the Regional Research Station of the Punjab Agricultural University. Both the sites are located in the Indo-Gangetic plains in the northwestern India. The climate of Ludhiana is subtropical, semi-arid with an annual rainfall of 733 mm. The climate of Gurdaspur is sub-humid and semiarid with annual rainfall of 887 mm. At both the sites about 80% of the annual rainfall is received during June to September when rice is grown. The mean monthly temperatures during the rice season varied from 29.3° to 33.8 °C at Ludhiana and from 28.1° to 33.0 °C at Gurdaspur. Some characteristics of surface (0–15 cm) soil samples at the 8 experimental locations are described in Table 1.

Description of treatments in different field experiments carried out during 2007–2010 at Ludhiana and Gurdaspur sites is given in Table 2. In any year, the treatments were similar in the experiments conducted both at Ludhiana and Gurdaspur sites was similar. A no-N control (T1) and a blanket recommendation treatment consisting of applying 120 kg N ha^{-1} in 3 equal split doses at 0, 21 and 42 DAT (T2) were kept in all the experiments.

The four fixed date adjustable N dose treatments tested in 2007 consisted of application of four combinations of fertilizer N doses at transplanting and at 21 DAT stages along with fertilizer N dose as per leaf colour at 42 and 56 DAT stages. These treatments are described as T3, T4, T5 and T6 in Table 2.

In 2008, along with treatments described for 2007 experiment, an additional treatment T7 consisted of applying 30 kg N ha^{-1} both at transplanting and at 21 DAT and adjustable fertilizer dose as per leaf colour at 42 and 56 DAT stages. During both 2007 and 2008 the experiments were laid out in a completely randomized block design with 3 replications.

In 2009, the experiments laid out in a split-plot design with 3 replications were carried out to compare the performance of the two fixed date adjustable dose treatments vis-à-vis blanket recommendation for three different rice cultivar, which constituted the main plots. The sub-plots consisted of four treatments: T1, T2 and the two fixed date adjustable N dose treatments T7 and T8 as described in Table 2. The two fixed-time adjustable dose treatments were designed keeping in view the results obtained in 2007

Table 2
Description of treatments in different field experiments carried out during 2007–2010 at Ludhiana and Gurdaspur sites.

N treatment	Fertilizer N application (kg N ha^{-1}) days after transplanting (DAT)			
	0 DAT	21 DAT	42 DAT	56 DAT
T1	0	0	0	0
T2	40	40	40	0
T3	0	20	ADa	ADb
T4	0	40	ADa	ADb
T5	30	20	ADa	ADb
T6	30	40	ADa	ADb
T7	30	30	ADa	ADb
T8	30	ADa	ADa	ADb

ADa: adjustable dose of 0, 30 or 45 kg N ha^{-1} was applied when leaf colour ≥LCC shade 5, between LCC shade 4 and 5 or <LCC shade 4, respectively; ADb: adjustable dose of 30 kg N ha^{-1} was applied when leaf colour <LCC shade 4.

Table 3
Age of nursery, date of transplanting, and date of maturity of different rice cultivars in different experiments and years.

Rice cultivar	Location	Year	Age of nursery at transplanting	Date of transplanting	Date of maturity
PR118,	Ludhiana	2007	40	22 June	06 October
PAU201	Gurdaspur	2007	35	23 June	04 October
PR118	Ludhiana	2008	40	24 June	06 October
PAU201	Gurdaspur	2008	34	24 June	07 October
PAU201	Ludhiana	2009	33	26 June	08 October
PUSA44	Ludhiana	2009	40	26 June	12 October
HKR127	Ludhiana	2009	34	26 June	06 October
PR108	Gurdaspur	2009	35	03 July	14 October
PAU201	Gurdaspur	2009	34	03 July	16 October
PUSA44	Gurdaspur	2009	39	03 July	18 October
PR114	Ludhiana	2010	36	01 July	21 October
PR116	Ludhiana	2010	36	01 July	23 October
PR118	Ludhiana	2010	36	01 July	25 October
PR120	Ludhiana	2010	36	01 July	12 October

and 2008 experiments and to keep options for applying more N in case the crop needs it in field with low N supplying capacity or in a year with favorable season for rice. While basic application of 30 kg N ha^{-1} was an integral part of both the treatments, LCC guided N management was tried either at 21, 42 and 56 DAT (T8) or at 42 and 56 DAT (T7).

In 2010, the fixed time adjustable dose treatment (T8, Table 2) consisting of applying 30 kg N ha^{-1} at transplanting +0, 30 or 45 kg N ha^{-1} at leaf colour ≥LCC shade 5, between LCC shade 4 and 5 or <LCC shade 4 at both 21 and 42 DAT +30 kg N ha^{-1} at leaf colour <LCC shade 4 at 56 DAT, was tested vis-à-vis a no-N control (T1) and a blanket recommendation treatment consisting of applying 120 kg N ha^{-1} in 3 equal split doses at 0, 21 and 42 DAT (T2). The evaluation of the fixed time adjustable dose treatment was carried at Ludhiana on four different rice cultivars. In all the experiments, the LCC used was manufactured by Nitrogen Parameters, Chennai, India as per specifications given by IRRI (1996).

After removing crop residues, the land was ploughed, puddled, and leveled for transplanting 4–5-week-old rice seedlings at 20 cm × 15-cm spacing during 22 June to 03 July in 25–36 m^2 treatment plots in different experiments and years. A dose of 26 kg P ha^{-1} [as $Ca(H_2PO_4)_2$], 25 kg K ha^{-1} (as KCl) and 10 kg Zn ha^{-1} (as $ZnSO_4{\cdot}7H_2O$) was incorporated into the soil before last puddling. During the rice season, along with rainfall, irrigation was provided using both well and canal water. Plots were kept flooded for 3 week after transplanting; thereafter, rice was irrigated at 2-day intervals. Although the soil did not remain flooded for more than 8–10 h after irrigation, anaerobic conditions prevailed for more than 75% of the rice growth period. Hand weeding was done, and pest control followed standard practices. Different rice varieties grown [cultivar PR 118 (duration 150 days) at Ludhiana in 2007, 2008 and 2010; cultivar PAU 201 (duration 144 days) at Gurdaspur in 2007 and 2008; cultivars PAU 201, PUSA 44 (duration 152 days) and HKR 127 (duration 140 days) at Ludhiana and cultivars PR 108 (duration 145 days), PAU 201 and PUSA 44 at Gurdaspur in 2009; cultivars PR 116 (duration 144 days), PR 114 (duration 145 days) and PR120 (duration 132 days) at Ludhiana in 2010] were modern semi-dwarf types with similar yield potential and harvest index. In Table 3 age of nursery, date of transplanting and date of maturity of different rice cultivars in different experiments and years are listed.

Crops were harvested by hand at ground level at maturity during 10 October to 28 October in different years and experiments. Grain and straw yields of rice were determined from an area of 12.6 to 15.4 m^2 for located at the center of each plot. Grains were separated from straw using a plot thresher, dried in a batch grain dryer, and weighed. Grain moisture was determined immediately after weighing. Grain weight for rice was expressed at 140 g kg^{-1} water content. Straw weights were expressed on oven-dry basis.

Grain and straw subsamples were dried at 70 °C and finely ground to pass through a 0.5-mm sieve. Nitrogen content in grain and straw was determined by digesting the samples in sulfuric acid followed by analysis for total N by a micro-Kjeldahl method (Yoshida et al., 1976). The N in grain plus that in straw was taken as the measure of total N uptake.

Analysis of variance was performed on yield parameters to determine effects of cultivars, N management treatments, and their interaction using IRRISTAT version 5.0 (International Rice Research Institute, Philippines). Mean comparison was performed based on the least significant difference (LSD) test at the 0.05 probability level.

The N use-efficiency measures, recovery efficiency (RE) (Dilz, 1988) and agronomic efficiency (AE) (Novoa and Loomis, 1981) were calculated as follows.

$$\text{RE}(\%) = \frac{\text{TNU in N fertilized plot} - \text{TNU in zero-N plot}}{\text{Quantity of N fertilizer applied in N fertilized plot}} \times 100$$

where TNU is the total N uptake in grain and straw.

$$\text{AE (kg grain/kg N applied)} = \frac{\text{Grain yield in N fertilized plot} - \text{Grain yield in zero-N plot}}{\text{Quantity of fertilizer N applied in N fertilized plot}}$$

3. Results and discussion

In 2007, both at transplanting and maximum tillering stage (21 DAT) fertilizer N doses were not applied on the basis of colour of the rice leaves and were fixed. Corrective doses of fertilizer N were applied at 42 and 56 DAT stages as guided by the colour of the top most fully expanded leaf of the rice plant. The data generated from this experiment (Table 4) revealed that prescriptive N management influenced not only grain yield and N uptake by rice but also the total N applied to rice when adjustable dose options based on the colour of the leaf are exercised at later growth stages. Keeping in view that the blanket recommendation for fertilizer N for transplanted rice in the region is to apply 40 kg N ha^{-1} each at 0, 21 and 42 DAT and the fact that there is high N demand by rice during the period between 21 and 42 DAT (De Datta, 1981), no risk combination of prescriptive and corrective N management for rice was found to be the application of 30 kg N ha^{-1} at transplanting, 40 kg N ha^{-1} at 21 DAT and application of 0, 30 or 45 kg N ha^{-1} at 42 DAT and another 0 or 30 kg N ha^{-1} at 56 DAT depending upon the intensity of the green colour of the first fully opened leaf (T6). This strategy resulted in application of only 30 kg N ha^{-1} at 42 DAT and no fertilizer N at 56 DAT so that total N applied turned out to be only 100 kg N ha^{-1} both at Ludhiana and Gurdaspur sites (Table 4). But the yield and N uptake were equivalent to those obtained by

Table 4
Fixed-time adjustable dose fertilizer N management using leaf colour chart at Ludhiana and Gurdaspur during 2007.

N treatment[a]	Fertilizer N applied (kg N ha^{-1}), days after transplanting					Gurdaspur				Ludhiana			
	0	21	42	56	Total	Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	RE_N[b] (%)	AE_N[c]	Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	RE_N[b] (%)	AE_N[c]
T1	0	0	0	0	0	4.71	82.3			3.45	52.5		
T2	40	40	40	0	120	7.24	157.3	62.5	21.1	4.92	95.4	35.8	12.2.
T3	0	20	45	0	65	6.28	134.7	80.6	24.3	4.03	73.3	32.0	8.9
T4	0	40	45	0	85	6.70	149.0	78.6	23.4	4.25	80.2	32.6	9.4
T5	30	20	45	0	95	6.92	159.5	81.3	23.3	4.47	82.3	31.4	10.7
T6	30	40	30	0	100	7.21	158.1	75.8	25.0	4.79	92.2	39.8	13.4
LSD (p = 0.05)						0.63	15.0	15.9	7.12	0.25	7.48	9.31	3.18

[a] Description of treatments is given in Table 2.
[b] Recovery efficiency of applied N.
[c] Agronomic efficiency [kg grain/kg N applied].

applying 120 kg N ha^{-1} as blanket recommendation. It suggested that there exists potential in achieving higher yield and/or saving in fertilizer N applications by applying fertilizers at fixed growth stages but based on colour of the leaves.

Not applying a dose of fertilizer N at transplanting of rice or applying only 20 kg N ha^{-1} at maximum tillering stage (21 DAT) (T3, T4 and T5) resulted in lower rice yields than those obtained by applying the blanket recommendation of 120 kg N ha^{-1} in 3 equal split doses (T2) (Table 4). It was particularly true at Ludhiana. As soil N supply quantified from yield and total N uptake in the no-N control plots (T1) at Gurdaspur was substantially higher than at Ludhiana, the treatments receiving 0 + 40 kg N ha^{-1} or 30 + 20 kg N ha^{-1} at transplanting and 21 DAT stage (T4 and T5) did not differ significantly than the highest yielding treatments. Only the treatment to which no N was applied at transplanting and 20 kg N ha^{-1} was applied at 21 DAT (T3) exhibited significantly less yield than the treatments to which fertilizer N was applied at both transplanting and maximum tillering stages. These results provided evidence that if corrective N management based on colour of rice leaves at 42 DAT and later stages is to be followed, prescriptive N management must ensure adequate supply of N both at transplanting and maximum tillering stages of rice.

The underlying philosophy of the experiments carried out in 2007 was continued in 2008. An additional treatment with prescriptive N management consisting of applying 30 kg N ha^{-1} each at transplanting and maximum tillering stages of rice (T7) was included. The corrective N management of applying 0, 30 or 45 kg N ha^{-1} at 42 DAT and 0 or 30 kg N ha^{-1} at 56 DAT depending upon intensity of the green colour of the first fully opened leaf from the top was similar to that in 2007 experiments. Results from experiment established both at Ludhiana and Gurdaspur sites showed similar trend (Table 5). As was expected, not applying a basal dose along with application of 20 or 40 kg N ha^{-1} at active tillering stage (21 DAT) (T3 and T4) could not help produce optimum yield of rice. Applying 30 kg N ha^{-1} at planting and 20 kg N ha^{-1} at maximum tillering (T5) was also not a suitable proposition even if as per criteria of using leaf colour, a dose of 45 kg N ha^{-1} was applied at panicle initiation stage. It was inferred from this experiment that a dose of 30 kg N ha^{-1} at transplanting and at least 30 kg N ha^{-1} at maximum tillering and a dose of 0, 30 or 45 kg N ha^{-1} at 42 DAT and 0 or 30 kg N ha^{-1} at 56 DAT depending upon colour of leaf (T7) was a better strategy. It resulted in higher fertilizer N use efficiency and produced optimum rice yield. With total N applications amounting to 105 kg N ha^{-1} with this strategy, the yield of rice was at par with that obtained by applying 120 kg N ha^{-1} as per blanket recommendation. Applying 40 kg N ha^{-1} instead of 30 kg N ha^{-1} at maximum tillering stage along with 30 kg N ha^{-1} at transplanting (T6) did not exert a positive influence on grain yield or N uptake and thus fertilizer N use efficiency.

Based on the outcome of the experiments conducted during 2007 and 2008, the treatments in 2009 experiments were further refined so as to reach at a strategy which can be given to farmers. Although in the experiments carried out in 2008 the two fixed date adjustable dose treatments with prescriptive N management consisting of 30 + 40 kg N ha^{-1} and 30 +30 kg N ha^{-1} at transplanting and 21 DAT (T6 and T7) performed very similarly, the two treatments could have differed significantly in a favorable climate year. Thus in 2009, along with the treatment consisting of supplying a dose of 30 kg N ha^{-1} both at transplanting and

Table 5
Fixed-time adjustable dose fertilizer N management using leaf colour chart at Ludhiana and Gurdaspur during 2008.

N treatment[a]	Fertilizer N applied (kg N ha^{-1}), days after transplanting					Gurdaspur				Ludhiana			
	0	21	42	56	Total	Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	RE_N[b] (%)	AE_N[c]	Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	RE_N[b] (%)	AE_N[c]
T1	0	0	0	0	0	4.95	65.7			3.82	47.1		
T2	40	40	40	0	120	8.14	125.9	50.2	26.6	6.32	112.7	54.7	20.8
T3	0	20	45	0	65	7.39	97.5	48.9	37.5	5.16	76.0	44.4	20.6
T4	0	40	45	0	85	7.70	110.8	53.1	32.4	5.48	87.7	47.7	19.5
T5	30	20	45	0	95	7.95	118.1	55.2	31.5	5.93	93.6	49.7	22.2
T6	30	40	45	0	115	8.43	131.7	57.4	30.2	6.21	106.1	51.3	20.8
T7	30	30	45	0	105	8.31	123.6	55.2	31.9	6.29	103.7	55.6	23.5
LSD (p = 0.05)						0.204	4.93	5.83	1.97	0.533	6.88	6.77	5.28

[a] Description of treatments is given in Table 2.
[b] Recovery efficiency of applied N.
[c] Agronomic efficiency [kg grain/kg N applied].

Table 6
Need based N management in rice cultivars using leaf colour chart by applying fertilizer at fixed crop growth stages at Ludhiana during 2009.

Cultivar	N treatment[a]	Fertilizer N application (kg N ha^{-1}), days after transplanting					Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	RE_N[b] (%)	AE_N[c]
		0	20	42	58	Total				
PAU 201	T1	0	0	0	0	0	3.63	60.4		
	T2	40	40	40	0	120	7.35	127.0	55.5	31.0
	T7	30	30	30	30	120	7.44	126.3	54.9	31.7
	T8	30	45	30	30	135	8.22	140.7	59.5	34.0
PUSA 44	T1	0	0	0	0	0	3.44	57.3		
	T2	40	40	40	0	120	6.30	112.3	43.3	22.2
	T7	30	30	30	30	120	6.40	112.8	43.7	23.1
	T8	30	45	30	30	135	6.87	121.8	45.5	24.0
HKR 127	T1	0	0	0	0	0	3.54	60.7		
	T2	40	40	40	0	120	6.62	115.7	46.2	24.9
	T7	30	30	30	30	120	6.80	117.1	47.3	26.4
	T8	30	45	30	30	135	7.11	130.0	51.6	25.7
LSD (p = 0.05): cultivar							0.555	6.84	3.99	3.82
Fertilizer treatment							0.216	5.14	3.90	1.46
Cultivar × fertilizer treatment							0.375	8.91	6.76	2.52

[a] Description of treatments is given in Table 2.
[b] Recovery efficiency of applied N.
[c] Agronomic efficiency [kg grain/kg N applied].

maximum tillering, and a dose of 0, 30 or 45 kg N ha^{-1} at 42 DAT and 0 or 30 kg N ha^{-1} depending upon colour of the leaf (T7), another treatment (T8) was tried in which prescriptive N dose consisted of applying 30 kg N ha^{-1} only at transplanting and corrective N doses consisted of applying 0, 30 or 45 kg N ha^{-1} at maximum tillering (21 DAT) as well as panicle initiation (42 DAT) and 0 or 30 at initiation of flowering (around 56 DAT) as per leaf colour. The results for different rice cultivars are listed in Tables 6 and 7.

Analyzing the performance of the two fixed time adjustable dose fertilizer N application treatments revealed that when a fixed dose of 30 kg N ha^{-1} was applied at 21 DAT (T7), total N applied was 120 kg N ha^{-1} and grain yield level was at par with blanket recommended dose. On the other hand, when there was an option of applying 0, 30 or 45 kg N ha^{-1} based on colour of the leaf at 21 DAT (T8), a dose of 45 kg N ha^{-1} was applied for all the three cultivars leading to total N application of 135 kg N ha^{-1} but with grain yield levels that were significantly higher than those obtained by following blanket recommendation (T2) or treatment T7. These results clearly show that in a favorable year when yields of rice are expected to be high, requirement of the crop at maximum tillering stage can be high and if adequate fertilizer N is not supplied at this time it can lead to yield loss. At Gurdaspur too, the performance of the treatment T8, in which need based fertilizer N was applied both at maximum tillering and panicle initiation stages was the best among all the treatments on the basis of grain yield and total amount of fertilizer N applied (Table 7). Since soil N supplying capacity at Gurdaspur site was better than at Ludhiana (as indicated by yield and N uptake by rice in the no-N control plots), the highest yields could be achieved by applying 120 kg N ha^{-1} by following blanket recommendation. When fixed date adjustable dose treatment consisting of applying need based fertilizer N as per leaf colour was followed at maximum tillering stage (21 DAT), while 45 kg N ha^{-1} was applied in case of rice cultivar PR108, only 30 kg N ha^{-1} was applied in case of the other two cultivars. Thus by applying either 120 or 105 kg N ha^{-1} as the total amount of fertilizer N, the highest yield of rice was recorded in the

Table 7
Need based N management in rice cultivars using leaf colour chart by applying fertilizer at fixed crop growth stages at Gurdaspur during 2009.

Cultivar	N treatment[a]	Fertilizer N application (kg N ha^{-1}), days after transplanting					Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	RE_N[b] (%)	AE_N[c]
		0	23	45	56	Total				
PR 108	T1	0	0	0	0	0	4.67	69.1		
	T2	40	40	40	0	120	8.45	142.1	60.9	31.5
	T7	30	30	45	0	105	7.96	128.6	56.7	31.3
	T8	30	45	45	0	120	8.53	140.1	59.2	32.2
PAU 201	T1	0	0	0	0	0	4.84	73.7		
	T2	40	40	40	0	120	9.40	157.8	70.1	38.0
	T7	30	30	45	0	105	9.53	155.1	77.5	44.7
	T8	30	30	45	0	105	9.50	153.9	76.4	44.4
PUSA 44	T1	0	0	0	0	0	4.86	70.8		
	T2	40	40	40	0	120	8.21	137.1	55.2	27.9
	T7	30	30	45	0	105	8.49	139.5	65.5	34.6
	T8	30	30	45	0	105	8.51	139.8	65.7	34.8
LSD (p = 0.05): cultivar							0.169	5.86	5.57	1.72
Fertilizer treatment							0.169	4.33	4.19	1.58
Cultivar × fertilizer treatment							0.293	7.50	7.27	2.74

[a] Description of treatments is given in Table 2.
[b] Recovery efficiency of applied N.
[c] Agronomic efficiency [kg grain/kg N applied].

Table 8
Need based N management in four rice cultivars using leaf colour chart by applying fertilizer at fixed crop growth stages at Ludhiana during 2010.

Cultivar	N treatment[a]	Fertilizer N application (kg N ha^{-1}) days after transplanting (DAT)					Grain yield (t ha^{-1})	Total N uptake (kg ha^{-1})	RE_N[b] (%)	AE_N[c]
		0	21	42	56	Total				
PR 118	T1	0	0	0	0	0	3.15	54.6		
	T2	40	40	40	0	120	6.26	119.4	54.0	25.9
	T8	30	30	30	0	90	6.19	115.3	67.4	33.8
PR 120	T1	0	0	0	0	0	3.35	57.3		
	T2	40	40	40	0	120	6.34	120.2	52.4	24.9
	T8	30	30	30	0	90	6.22	111.9	60.6	31.9
LSD (p = 0.05): cultivar							0.147	1.96	5.50	2.39
Fertilizer treatment							0.293	5.45	5.45	3.94
Cultivar × fertilizer treatment							0.414	7.71	7.71	5.57
PR 114	T1	0	0	0	0	0	3.21	49.7		
	T2	40	40	40	0	120	6.39	124.9	62.7	26.5
	T8	30	30	30	0	90	6.46	108.0	64.8	36.1
PR 116	T1	0	0	0	0	0	3.23	51.5		
	T2	40	40	40	0	120	6.49	121.1	58.1	27.2
	T8	30	30	30	0	90	6.42	108.8	63.7	35.4
LSD (p = 0.05): cultivar							0.285	2.49	0.70	3.42
Fertilizer treatment							0.195	3.97	4.77	2.62
Cultivar × fertilizer treatment							0.276	5.62	6.76	3.70

[a] Description of treatments is given in Table 2.
[b] Recovery efficiency of applied N.
[c] Agronomic efficiency [kg grain/kg N applied].

treatment T8 in which after applying 30 kg N ha^{-1} at transplanting fertilizer N at the remaining three stages was applied as per the leaf colour. The values of agronomic and recovery efficiency when averaged over all the three cultivars both at Ludhiana and Gurdaspur also showed that among the two fixed date adjustable dose treatments only the treatment T8 performed significantly better than the blanket recommendation treatment (Tables 6 and 7). The total amount of N applied following this strategy can range from 30 to 150 kg N ha^{-1} and is wider than that recorded by following real time N management in different studies (Varinderpal-Singh et al., 2007; Yadvinder-Singh et al., 2007) carried out in South Asia.

In 2010, performance of the fixed time adjustable dose treatment consisting of applying 30 kg N ha^{-1} at transplanting +0, 30 or 45 kg N ha^{-1} at leaf colour ≥LCC shade 5, between LCC shade 4 and 5 or <LCC shade 4 at both 21 and 42 DAT +30 kg N ha^{-1} at leaf colour <LCC shade 4 at 56 DAT (T8) was studied vis-à-vis blanket recommendation of 120 kg N ha^{-1} applied in 3 equal split doses on four rice cultivars differing in duration of maturity. The results from the two field experiments as listed in Table 8 confirmed the superiority of this treatment as in all the four cultivars it resulted in application of 90 kg N ha^{-1} but produced rice grain yield that was at par with the yield obtained by applying 120 kg N ha^{-1} in the blanket recommendation treatment (T2). The fertilizer N use efficiency measures for the fixed time adjustable dose treatment were also significantly better than those for the blanket recommendation treatment.

The site-specific N management to increase fertilizer N use efficiency of irrigated rice described by Dobermann et al. (2002) involves N application based on the crop N demand determined by climatic factors (solar radiation and temperature) and indigenous N (Cassman et al., 1996) at critical growth stages with upward or downward adjustments of N topdressings based on leaf N status measured with chlorophyll meter (Peng et al., 1996). In this approach, the timing and number of N applications are fixed while the rate of N topdressing varies across seasons and locations (Peng et al., 2010). Although the approach followed in the present study is not exactly similar to this site-specific N management approach, but the element of adjusting the actual rates at tillering and panicle initiation as per leaf N status has been extended in a way that total N to be applied in the season is also defined. Total amount of N to be applied varies from 30 to 150 kg N ha^{-1} and it very well covers the range of grain yield responses of irrigated transplanted rice in the region. The blanket recommendation of 120 kg N ha^{-1} for the region also provides a fairly good estimate of the total N to be applied in the region. The results of the present investigation show that adjustable doses of N are to be applied at four growth stages of rice. While in the blanket recommendation for applying fertilizer N to rice, three growth stages have been earmarked, it has been observed in the studies carried out by Yadvinder-Singh et al. (2007) that applying fertilizer N at more than four growth stages of rice does not lead to yield benefit. Bijay-Singh et al. (1991) could not observe yield benefit in rice even when fertilizer N was applied in 10 split doses rather than three.

In the site-specific N management approach described by Dobermann et al. (2002), N top dressing were adjusted by ±10 kg N ha^{-1} according to leaf N status as measured by LCC. However, on the basis of results from 144 on-farm experiments, Peng et al. (2010) concluded that in-season adjustment of N rate by ±10 kg N ha^{-1} may be inadequate because more adjustment could be needed when yield level and the magnitude of N response are high. The finding of Peng et al. (2010) that site-specific N management experiments in China reduced N fertilizer by 32% and increased grain yield by 5% compared with farmers' practices also corroborates the results obtained in the present investigation that benefit of following fixed date adjustable dose N management was expressed in reduced N applications most of the times. Only in favorable climate years (as in 2009 experiments in the present study) yield benefits were also obtained. The extent of reduction in fertilizer N use by following the fixed-time adjustable dose strategy in China was substantially high because fertilizer N rates tend to be much higher than those used in this study. Thus agronomic efficiency values recorded in the present investigation were substantially higher than those observed in Chinese studies (Peng et al., 2006, 2007; Wang et al., 2007). In fact in a number of instances (Gurdaspur in 2008 and 2009 and for cultivar PAU201 at Ludhiana in 2009) agronomic efficiencies higher than 25 kg grain/kg N indicate that higher yields and productivity could have been obtained with higher rates of N than those used in this study. It indicates that including an option of applying 60 kg N ha^{-1} at leaf colours less than LCC shade 3.5 may result in yield benefits. Nitrogen rates up to 60 kg N ha^{-1} are recommended with the fixed time adjustable dose approach described by Witt et al. (2007). As the conclusions drawn in the present investigation are based on 8 field experiments conducted during four rice seasons and at two sites, the emerging fixed-time adjustable dose strategy should be widely applicable. There was a large variation in the yield levels of rice observed during the four years and at the two experimental stations. The rice yield levels at Ludhiana site were, in general, less than at Gurdaspur site because soils there are coarser in texture than at Gurdaspur (Table 1). And in 2007, rainfall at Ludhiana during July, August and September (318.1 mm) was exceptionally less than the normal (513.6 mm) and in 2008 (590.2 mm), 2009 (728.5 mm) and 2010 (615.0 mm) during the same period. Thus rice yields and response to applied fertilizer N at Ludhiana in 2007 were exceptionally low than in other years.

According to Peng et al. (2010) the site-specific N management approach is a matured technology for improving both fertilizer N use efficiency and grain yield of irrigated rice crop but the challenge is to further simplify the procedure of site-specific N management. The results obtained in the present study constitute an important contribution in this direction. The guidelines for fixed-time adjustable dose application of N to transplanted rice as developed in the present investigation should be useful in any region provided LCC has the panel colours similar to the one being used in India. Since this LCC has panel colours different than the LCC currently promoted by IRRI (Witt et al., 2005), guidelines developed in this study do not replace the guidelines for the IRRI LCC as described by Witt et al. (2007).

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