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Full Length Research Paper

Calibrating the leaf color chart for rice nitrogen management in Northern Iran

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The high and inefficient use of Nitrogen (N) fertilizer continues to be a problem in rice (*Oryza sativa* L.) cultivation sites in Northern Iran. The leaf color chart (LCC) based N management can be used to optimize N application with crop demand or to improve existing fixed split N recommendations. We conducted a field experiment in 2008 at Amol region of Northern Iran, to determine the LCC critical value for N application in different rice genotypes. Treatments included 12 LCC based N management contained the combination of three critical levels of LCC (3, 4 and 5) with four levels of N application (20, 25, 30 and 35 kg ha^{-1}) for two rice genotypes which consist of Tarom-Hashemi and GRH-1 were compared with the zero N control and a recommended fixed time N splitting. Nitrogen was applied in form of urea as per treatment schedule and the LCCs assessed at 10 days intervals from 12 days after transplanting. Result showed a considerable opportunity to increase farmers yield and N use efficiency (NUE) levels through improved N management with the LCC. The critical LCC value of 4 with 25 kg N ha^{-1} for Tarom-Hashemi and critical LCC value of 4 with 35 kg N ha^{-1} for GRH-1 were found to be suitable for guiding N application to achieve the highest grain yield for the Amol region of Northern Iran.

Key words: *Oryza sativa* L., N management, LCC, N use efficiency.

INTRODUCTION

Rice (*Oryza sativa* L.) is a major crop of 89 countries in the world and is the stable food for half of the world population (Nachimuthu et al., 2007). World rice production must increase by approximately 1.5% annually to meet the growing demand for food that will result from population growth and economic development (Rosegrant et al., 1995). Nitrogen (N) is the nutrient that most often limits crop production (Shukla et al., 2004). Cereals including rice accounted for approximately 50% of the worldwide N fertilizer utilized (IFA, 2009). Due to the fact that farmers in many parts of the word tend to apply N fertilizer in an inefficient excess of the requirements (Bijay-Singh et al. 2002), N recovery efficiency (RE_N) in rice plant is low. Based on a worldwide evaluation, RE_N has been found to be around 30% in rice (Krupnik et al., 2004). The RE_N is associated with large loss of N fertilizer from the soil plant system, which can and Yadvinder-Singh, 2003; Houshmandfar et al., 2008). The high and inefficient use of N fertilizer, particularly at high levels of yield and cropping intensity, can also result in crop lodging, increased pest and disease infestation, and reduced profitability for farmers. The development and promotion of more efficient practices for N fertilizer management in rice consequently remain a high priority for increasing profitability of rice farming while protecting the environment (Buresh et al., 2004; Dawe et al., 2004). Fixed time recommended N split applications at specified growth stages is the most common practice following by the farmers (Navarro, 1991). In this called real-time, approach to N management the timing of N fertilizer applications is determined through periodic monitoring of crop N status (Witt et al., 2004). Monitoring plant N status is important in improving the balance between crop N demand and N supply from soil and applied fertilizer (Cassman et al., 1994). As leaf N content is closely related to photosynthetic rate (Peng et al., 1993) and biomass production (Kropff et al., 1993) it is a sensitive indicator of the dynamic changes in crop N demand

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during a growing season. The direct measurement of leaf N concentration by laboratory procedure is laborious, time concerning and costly (Nachimuthu et al., 2007). Such procedures have limited use as a diagnostic tool for optimizing N topdressing because of the extensive time delay between sampling and obtaining results (Yang et al., 2003). Two simple, quick and non destructive tools available for in situ monitoring of leaf N status in rice are the chlorophyll meter, also known as SPAD (soil plant analysis development) meter, and LCC (Balasubramanian et al., 1998; Peng et al., 1996). A chlorophyll meter can provide a quick estimate of the leaf N status, but it is relatively expensive (Murshedul-Alam et al., 2005). The LCC on the other hand is inexpensive, simple, and an easy-to-use alternative to monitor the relative greenness of the rice leaf as an indicator of crop N status (Shukla et al., 2004; Balasubramanian et al., 2003). The concept is based on results that show a close link between leaf chlorophyll content and leaf N content. Moreover, leaf-area-based N concentration varies within a narrow range at different growth stage (Shukla et al., 2004). It has been successfully used for rice (Murshedul-Alam et al., 2005) and wheat (Houshmandfar, 2009). The LCCs used in Asia are typically a durable plastic strip about 7 cm wide and 13 to 20 cm long, containing four to six panels that range in color from yellowish green to dark green. With a real-time approach to N management, farmers monitor the color of rice leaves at 7 to 10 days intervals and apply N fertilizer wherever leaves become more yellowish green than the critical color on the LCC. Bijay-Singh et al. (2002) indicated that N management based on LCC shade 4 helped avoid over application of N to rice at Northwestern India.

Nachimuthu et al. (2007) reported that N management based on LCC shade 4 which received 20 kg N ha^{-1} each time with a total dose of 60 kg N ha^{-1} recorded comparable yield with 120 kg N ha^{-1} in four equal split, with saving of 50% N fertilizer.

Even, real-time N management with the LCC has been under evaluation in fields in Asia since the late 1990s (Murshedul-Alam et al., 2005), limited information is available on the accuracy of LCC in estimating leaf N status of rice plant (Nachimuthu et al., 2007). The use of LCC for scheduling N application may not be uniformly applicable to all varieties that differ in inherent leaf color and regions that differ in climate, thereby necessitating individual or group standardization in different cultivated areas (Sheoran et al., 2004). Hence, the specific objective of this study was to evaluate the fixed critical reading approaches for real-time N fertilizer management for rice plant, Tarom-Hashemi and GRH-1 Genotypes, based on LCC at the Amol region of northern Iran.

MATERIALS AND METHODS

Description of the study site

A field experiment during rice cultivated season in 2008 was conducted with paddy rice genotypes in the calcareous soil of a research farm at the Amol region (36°36´ N, 52°23´ E; 28 m above mean sea level), located in Mazandaran state of northern Iran. The climate of Amol is humid subtropical. The average annual rainfall is 848.4 mm year^{-1}, about 20% of which occurs during rice cropping (May-September) season. Mean maximum and minimum temperatures are 31 and 20°C during May to September. Soil thermal and moisture regimes are Ustic and Thermic, respectively (Soil Survey Staff, 2010). Soil sample for site characterization were collected at 0 to 15 cm depth from 10 different locations in the field using a 5 cm diameter auger. The sample was air-dried, ground and sieved through a 2 mm sieve for nutrient analysis using procedures described by Chaturvedi et al. (2006). The soil is slightly alkaline (16.5% $CaCO_3$) and has a clay loam texture (27.9% Sand, 27.2% Clay and 44.9% Silt), with an electrical conductivity (EC_e) of 1.4 dS m^{-1}, pH of 7.4 (saturated paste), cation exchange capacity (CEC) of 31.1 c mol$_c^+$ kg^{-1}, Organic C of 1.8%, Kjeldahl N of 0.17%, Olsen P of 8.16 and K of 160 mg kg^{-1}.

Experimental design and treatments

The experiment was laid out in a split-plot design with two rice genotypes included Tarom-Hashemi (traditional, 118 to 123 days duration, high-value crop) and GRH-1 (hybrid, 128 to 135 days duration, high yield potential) in the main plots and 14 fertilizer N management treatments in subplots in three replications (Table 1). The fertilizer N management treatments included 12 LCC based N management consist of the combination of three critical levels of LCC (LCC≤3, LCC≤4 and LCC≤5) with four levels of N application (20, 25, 30 and 35 kg ha^{-1}) were compared with the zero N control and a recommended splits (100 kg ha^{-1} N for Tarom-Hashemi and 120 kg ha^{-1} N for GRH-1). In the recommended N rate treatment, N was applied in three equal splits (1/3, 1/3 and 1/3 total kg N ha^{-1}) at transplanting (basal), midtillering and panicle initiation. Nitrogen was applied in form of urea as per treatment schedule.

Crop management

The experimental site was plowed on 12 Feb. 2008 and repeated on 10 May 2008. Then the site was puddled and leveled for transplanting rice. Four-week old seedlings were transplanted at 25 · 25 cm spacing in 30 m^2 (5 · 6 m) plots on 20 May 2008. A dose of 100 kg P_2O_5 ha^{-1}, 100 kg K_2O ha^{-1} and 5 kg $ZnSO_4$ ha^{-1} were applied into the soil before last puddling. The plants were grown under assured irrigation with 16 irrigations in addition to rainfall. At each irrigation, 3 cm of water was applied and the interval between two irrigations depended on the disappearance of water. Hand-weeding was done and standard cultural practices were carried out until the crop was mature. Plants were harvested at ground level at maturity on 8 September, 2008 (Tarom-Hashemi) and 14 September, 2008 (GRH-1).

Leaf color chart measurement

The LCC jointly developed by International Rice Research Institute (IRRI) and Philippine Rice Research Institute (PhilRice), consisting of six green shades from yellowish green to dark green, showing increasing greenness with increasing number, was used in this study. The chart was used to take 10 days interval reading starting12 DAT. Fifteen disease-free rice plants were randomly selected in the plot, and the color of the youngest fully expanded leaf of the selected plant was compared by placing its middle part on top of the color strip in the chart. If 2/3 or more leaves read equal or below the treatments critical value (of LCC 3, 4 or 5), a dose of 20, 25, 30 or 35 kg N ha^{-1} was applied as per treatment

Table 1. Treatment used in the rice experimental field in 2008 at Amol, Iran.

N management details	Total N applied (kg ha^{-1})		No. of splits		Time of N application (DAT) ‡	
	§G_1	G_2	G_1	G_2	G_1	G_2
Control	0	0	-	-	-	-
G_1 recommended splits: 1/3, 1/3 and 1/3 total kg N ha^{-1}	100	-	3	-	1, 25, 50	-
G_2 recommended splits: 1/3, 1/3 and 1/3 total kg N ha^{-1}	-	120	-	3	-	1, 25, 50
20 kg N ha^{-1} at LCC+≤3	60	60	3	3	22, 32, 52	22, 32, 42
25 kg N ha^{-1} at LCC≤3	75	75	3	3	22, 32, 52	22, 32, 42
30 kg N ha^{-1} at LCC≤3	60	90	2	3	22, 42	22, 32, 42
35 kg N ha^{-1} at LCC≤3	70	105	2	3	22, 42	22, 42, 52
20 kg N ha^{-1} at LCC≤4	100	100	5	5	12, 22, 32, 42, 52	12,22, 32, 42, 52
25 kg N ha^{-1} at LCC≤4	100	125	4	5	12, 32, 42, 52	12, 22, 32, 42, 52
30 kg N ha^{-1} at LCC≤4	120	150	4	5	12, 32, 42, 52	12, 22, 32, 42, 52
35 kg N ha^{-1} at LCC≤4	140	140	4	4	12, 32, 42, 52	12, 22, 42, 52
20 kg N ha^{-1} at LCC≤5	100	120	5	6	12, 22, 32, 42, 52	12, 22, 32, 42, 52, 62
25 kg N ha^{-1} at LCC≤5	100	125	4	5	12, 22, 32, 42	12, 22, 32, 42, 52
30 kg N ha^{-1} at LCC≤5	120	150	4	5	12, 22, 32, 42	12, 22, 32, 42, 52
35 kg N ha^{-1} at LCC≤5	140	140	4	4	12, 22, 32, 42	12, 22, 42, 52

†LCC, leaf color chart, ‡DAT, days after transplanting, §G, Genotypes: G_1, Tarom-Hashemi and G_2, GRH-1 (hybrid).

schedule (Table 1). LCC readings were taken up to 50% flowering stage.

Plant sampling and analysis

Grain and straw yields were determined from an area of 12 m^2 located in the center of each treatment plot at harvestable maturity. Grain yields are reported at 14% water content fresh weight. Grain weight was determined after separated from straw. The grain plus separated straw were dried in an oven at 70°C for 48 h to achieve constant weight. Nitrogen content in grain and straw was determined by digesting the samples in sulfuric acid (H_2SO_4), followed by analysis of total N by the Kjeldahl method (Bremner and Mulvaney, 1982) using a Kjeltec autoanalyzer. The N in grain plus that in straw was taken as the measure of total N uptake.

Data analysis

The agronomic efficiency (AE_N), apparent recovery efficiency (RE_N) and partial factor productivity (PFP_N) from applied N fertilizer were calculated as follows (Cassman et al., 1998): AE_N = kg grain increase kg^{-1} N applied = (Y_N - Y_0/F_N) where Y_N is the rice grain yield (kg ha^{-1}) at a certain level of applied fertilizer N (F_N, kg ha^{-1}), and Y_0 is the rice grain yield (kg ha^{-1}) measured in a control plot with no N application. RE_N = kg N taken up kg^{-1} N applied = (U_N - U_0)/F_N where U_N is the total N in aboveground plant biomass at physiological maturity (kg ha^{-1}) in a plot receiving N without N addition. PFP_N = kg rice grain yield kg^{-1} N applied = Y_N/F_N.

The analysis of variance (ANOVA) was performed on yield and N efficiency parameter to determine the effects of genotypes, fertilizer N management treatments, and their interactions using SAS software version 8 (SAS Inst. 1999). Duncan's multiple range test (DMRT) at the 0.05 level of probability was used to evaluate the difference among treatment means.

RESULTS AND DISCUSSION

Grain yield and N uptake

The effects of genotype, N management and genotype × N management interaction were significant for grain yield and N uptake (Table 3), and a significant positive response of rice grain yield and total N uptake to N application relative to the zero N control was observed in all treatments for both genotypes (Table 4).

In Tarom-Hashemi, using the criteria of applying 20, 25, 30 and 35 kg N ha^{-1} each time the LCC value falls below 3 resulted in rice grain yield and total N uptake were lower to those obtained in three fixed schedule recommended N (Table 3). However the treatment with applying 25 kg N ha^{-1} at LCC value of 3 with a total application of 75 kg N ha^{-1} had a comparable grain yield and total N uptake with three splits recommended N treatment with a saving of 25% N fertilizer. This result is in contrast to the findings of Shukla et al. (2004) in India that N management based on a critical LCC value of 3 could produce yields in Basmati-370 (traditional, high-value crop) higher to those obtained in three fixed time splits. This may be due to difference in rice genotypes and growing conditions between the two studies. Total N applied at the LCC critical value of 4 with 20 and 25 kg N ha^{-1}, and LCC value of 5 with 20 and 25 kg N ha^{-1} was the same as in fixed schedule recommended N treatment (Table 1). However the grain yield and total N uptake were higher for LCC based N treatments than for fixed schedule recommended N application (Table 3). The

Table 2. Analysis of variance for the effect of different fertilizer N management criteria on grain yield, total N uptake, AE_N, RE_N and PFP_N of two rice Genotypes in 2008 at Amol, Iran.

Source of variation	Analysis of variance for grain yield and N uptake			Analysis of variance for AE_N, RE_N and PFP_N			
	df	F value (grain yield)	F value (N uptake)	df	F value (AE_N) †	F value (RE_N) ‡	F value (PFP_N) §
Replication	2	0.14	58.3978*	2	0.21	34.4814 *	0.23
Genotype (G)	1	48969.72 **	47344.71**	1	13155.28 **	1199.99 **	45898.90 **
N management (N)	13	1142.63 **	1902.74**	12	179.93 **	340.73 **	4050.99 **
G × N	13	296.69 **	59.12**	12	33.36 **	38.21 **	307.62 **
Residual	54			50			

*Significant at $P < 0.05$, **Significant at $P < 0.01$, † AE_N, agronomic efficiency, ‡ RE_N, apparent recovery efficiency, § PFP_N, partial factor productivity.

highest grain yield for Tarom-Hashemi with an increase of approximately 7% grain yield compare with the recommended splits method, obtained at the treatment with applying 25 kg N ha^{-1} at LCC value of 4 with a total application of 100 kg N ha^{-1} (Table 3).

In Hybrid GRH-1, using the LCC critical value of 3 resulted in rice grain yield and total N uptake lower to those obtained in three fixed schedule recommended N (Table 4). The splits time of LCC based N management with LCC value of 4 with 25, 30 and 35 kg N ha^{-1} were found to be same as in LCC value of 5 with 25, 30 and 35 kg N ha^{-1} (Table 1). Total N applied with the LCC value of 5 with 20 kg N ha^{-1} was the same as in fixed schedule recommended N treatment (Table 1). However grain yield and total N uptake were higher for LCC based N treatment than for fixed schedule recommended N application (Table 4). The Highest grain yield (8544 kg ha-1) for GRH-1 genotype achieved with the total application of 140kg N ha^{-1} at the LCC value of 4 with 35 kg N ha^{-1} which doesn't have significant different with application of 150 kg N ha^{-1} at the LCC value of 4 with 30kg N ha^{-1} (Table 4). This means that GRH-1 required 20 kg ha^{-1} more N for LCC based N management than for fixed schedule recommended N application. The same result was reported by the other researchers that N management based on LCC shade 4 could produce yields in Hybrid PHB-71 higher to those obtained in three fixed schedule recommended N (Shukla et al., 2004). The lower yield and total N uptake with fixed schedule recommended N application method than with LCC managed N in Tarom-Hashemi and GRH-1 genotypes could be associated with suboptimal rates of N application in the recommendation, which could have limited rice growth. This result indicate that the current recommendation of fixed time split N applications at specified growth time is not adequate to synchronize N supply with actual crop N demand due to poorly designed N splitting and variations in crop N demand (Bijay-Sing et al., 2002; Nachimuthu et al., 2007). Furthermore, N application in recommended splits are not based on the indigenous N supply (INS) (Shukla et al., 2004). The INS is defined as total plant N uptake at physiological maturity in zero N plots, which represents all sources of N (soil, organic materials, rhizosphere N fixation, crop residues, rainfall, irrigation water, etc.) available to crops during the growing season (Dobermann et al., 2003). This varies with crop, soil and cropping season (Adhikari et al., 1999; Stalin et al., 1996). The INS capacity in this study was 57.9 ± 1 and 61.3 ± 1.3 kg N ha^{-1} for Tarom-Hashemi and GRH-1, respectively.

Nitrogen fertilizer use efficiency

The effects of genotype, N management and genotype × N management interaction were significant for N agronomic efficiency (AE_N), apparent recovery efficiency (RE_N) and partial factor productivity (PFP_N) (Table 2). Generally AE_N, RE_N and PFP_N are greater when less N fertilizer was used, but this was achieved with the use of the LCC without sacrificing yield. The AE_N for most of the LCC based N management treatments was the same or higher as in fixed schedule recommended N treatment. The exceptions were LCC based treatment value of 4 with 35 and value of 5 with 30 and 35 kg N ha^{-1} with a total N application of 140, 120 and 140 kg N ha^{-1} respectively, for Tarom-Hashemi (Table 3), and the LCC value of 4 with 30 kg N ha^{-1} with a total N application of 150 kg N ha^{-1} for GRH-1 (Table 4). This failure to increase AE_N was may be due to the large amount of N applied (Murshedul-Alam et al., 2005).

Based on published data (Dobermann et al., 2004), the RE_N exceeding 50% with consistent high grain yield are regarded as efficient for rice. In this study, total N net returns were 8 to 19% higher in LCC-based N management than in fixed- time N application with same total N applied. The LCC value of 4 with 25 kg N ha^{-1} with a total N application of 100 kg N ha_{-}^{1} and highest grain yield level in Tarom-Hashemi genotype had an efficient RE_N of approximately 54 kg kg^{-1} (Table 3). In GRH-1, the

Table 3. Grain yield, total N uptake, AEN, REN and PFPN of Tarom-Hashemi rice genotype using different fertilizer N management criteria in 2008 at Amol, Iran.

N management treatments	Total N applied ($kg\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Total N uptake ($kg\ ha^{-1}$)	AE_N § ($kg\ kg^{-1}$)	RE_N ¶ ($kg\ kg^{-1}$)	PFP_N # ($kg\ kg^{-1}$)
Genotype: Tarom-Hashemi						
Control	0	† 2736 i	57.9 k	-	-	-
Recommended splits	100	3953 e	103.7 g	12.17 d	38.10 k	39.53 f
20kg N ha^{-1} at LCC‡≤3	60	3796 g	95.7 i	17.67 a	62.97 a	63.27 a
25kg N ha^{-1} at LCC≤3	75	3871 f	100.7 h	15.08 b	57.03 c	51.62 c
30kg N ha^{-1} at LCC≤3	60	3611 h	91.1 j	14.60 b	55.30 d	60.19 b
35kg N ha^{-1} at LCC≤3	70	3637 h	99.8 h	12.88 c	59.83 b	51.96 c
20kg N ha^{-1} at LCC≤4	100	4082 bc	107.7 f	13.46 c	49.80 f	40.82 e
25kg N ha^{-1} at LCC≤4	100	4226 a	112.1 e	14.70 b	54.20 e	42.26 d
30kg N ha^{-1} at LCC≤4	120	4189 a	115.3 c	12.11 d	47.67 g	34.91 g
35kg N ha^{-1} at LCC≤4	140	4106 b	119.9 a	9.85 f	44.23 i	29.33 i
20kg N ha^{-1} at LCC≤5	100	4079 bc	107.5 f	13.39 c	49.60 f	40.79 e
25kg N ha^{-1} at LCC≤5	100	4053 bcd	108.3 f	13.17 c	50.40 f	40.53 e
30kg N ha^{-1} at LCC≤5	120	4026 cd	113.4 d	10.83 e	46.23 h	33.56 h
35kg N ha^{-1} at LCC≤5	140	4001 de	117.1 b	9.04 g	42.23 j	28.58 j

† Within a column, means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's multiple range test. ‡ LCC, leaf color chart. § AEN, agronomic efficiency. ¶ REN, apparent recovery efficiency. # PFPN, partial factor productivity.

LCC value of 4 with 25 kg N ha^{-1} with a total N application of 125 kg N ha^{-1} and a comparable grain yield with the highest level find efficient in RE_N parameter (Table 4).

The PFP_N in both rice genotypes was improved by the LCC based N management compared with the fixed schedule recommended N method, since in the situation of same total N application, all the LCC based N management treatments had higher N partial factor productivity (Tables 3 and 4).

Improving the synchronization between crop N demand and the available N supply is an important key to improve N use efficiency (NUE). There is opportunity to reducing N application with the LCC with the use of a lower critical LCC value and the lower dose of N fertilizer applied whenever leaf color fell below a critical LCC value. Other evaluation of the LCC in rice production systems of Asia have often reported savings in N fertilizer use, which can result in increased NUE (Bijay-Singh et al. 2002). These results indicated that the application of N, based on LCC effectively matched the rice crop N demand.

Conclusion

Monitoring rice plant N status is an important subject with improving the balance between crop N demand and N supply from soil and applied fertilizer. In many field situations in Iran, more than 50% of applied N is lost due in part to the lack of synchrony of plant N demand with N supply. The LCC is simple and easy-to-use tool that can help farmers avoid overapplication of N in rice plant. The LCC based management in rice suggests that N application can be saved with no yield lose by appropriately revising the fertilizer recommendation. Thus, there is considerable opportunity to increase farmers yield and N recovery efficiency levels through improved N management with the LCC. The critical LCC value of 4 with 25 kg N ha^{-1} for Tarom-Hashemi and critical LCC value of 4 with 35 kg N ha^{-1} for GRH-1 were found to be suitable for guiding N application to achieve the highest grain yield for the Amol region of northern Iran. In the situation of using fixed-time split N recommendations, refining fixed-time split N recommendations periodically will be needed with the real-time N management to tackle high spatial and temporal variability in INS.

Table 4. Grain yield, total N uptake, AE_N, RE_N and PFP_N of GRH-1 rice genotype using different fertilizer N management criteria in 2008 at Amol, Iran.

N management treatments	Total N applied (kg ha^{-1})	Grain yield (kg ha^{-1})	Total N uptake (kg ha^{-1})	AE_N § (kg kg^{-1})	RE_N ¶ (kg kg^{-1})	PFP_N # (kg kg^{-1})
Genotype: GRH-1						
Control	0	† 4603 i	61.3 k	-	-	-
Recommended splits	120	7827 d	120.1 f	26.87 f	48.97 e	65.23 h
20kg N ha^{-1} at LCC‡≤3	60	6956 h	99.5 j	39.22 a	63.63 a	115.9 a
25kg N ha^{-1} at LCC≤3	75	7201 g	108.5 i	34.64 b	62.90 a	96.01 b
30kg N ha^{-1} at LCC≤3	90	7376 f	115.8 h	30.81 c	60.53 b	81.96 c
35kg N ha^{-1} at LCC≤3	105	7427 f	118.4 g	26.90 f	54.33 c	70.75 e
20kg N ha^{-1} at LCC≤4	100	7739 e	121.4 e	31.36 c	60.10 b	77.39 d
25kg N ha^{-1} at LCC≤4	125	8232 b	125.1 c	29.03 d	51.00 d	65.86 gh
30kg N ha^{-1} at LCC≤4	150	8544 a	128.7 b	26.17 g	44.93 f	56.96 j
35kg N ha^{-1} at LCC≤4	140	8507 a	130.5 a	27.89 e	49.40 e	60.77 i
20kg N ha^{-1} at LCC≤5	120	8007 c	123.8 d	28.37 e	52.07 d	66.73 f
25kg N ha^{-1} at LCC≤5	125	8264 b	125.8 c	29.29 d	51.57 d	66.12 fg
30kg N ha^{-1} at LCC≤5	150	8517 a	127.8 b	26.09 g	44.33 f	56.78 j
35kg N ha^{-1} at LCC≤5	140	8523 a	131.1 a	28.01 e	49.83 e	60.88 i

† Within a column, means followed by the same letter are not significantly different at the 0.05 level of probability by Duncan's multiple range test, ‡ LCC, leaf color chart, § AE_N, agronomic efficiency, ¶ RE_N, apparent recovery efficiency, # PFP_N, partial factor productivity.

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