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Establishment of threshold leaf colour greenness for need-based fertilizer nitrogen management in irrigated wheat (*Triticum aestivum* L.) using leaf colour chart

Varinderpal-Singh*, Bijay-Singh, Yadvinder-Singh, H.S. Thind, Gobinder-Singh, Satwinderjit-Kaur, Ajay Kumar, Monika Vashistha

Department of Soil Science, Punjab Agricultural University, Ludhiana 141 004, India

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ABSTRACT

Over and untimely application of fertilizer nitrogen (N) are the major constrains in improving fertilizer N recovery efficiency in irrigated wheat (*Triticum aestivum* L.). Large field to field and seasonal variability further lower fertilizer N recovery efficiency when broad based blanket recommendations are followed. Six field experiments were conducted during 2005 to 2009 at different locations to establish threshold leaf colour greenness to guide in-season need-based fertilizer N topdressings in wheat. Colour of the first top fully exposed leaf as measured by comparison with different shades of green colour on a leaf colour chart (LCC) and wheat grain yield were significantly correlated. The Cate-Nelson plot of leaf greenness expressed as LCC values against relative grain yield of 0.91 indicated that leaf greenness between LCC shade 4 and 5 may guide crop demand driven N applications in wheat. A series of experiments with progressive refinement in treatments were conducted to develop adequate need-based N management strategy using a single threshold LCC value in irrigated wheat. It was found that a dose of at least 25 kg N ha^{-1} should be applied at planting. At 1st irrigation (crown root initiation) stage leaf greenness cannot be quantified properly using LCC due to small leaf size and thus it did not lead to adequate fertilizer N management decision. At 2nd irrigation (maximum tillering) stage leaf colour of the first fully exposed leaf served as best indicator of inherent soil N supply as well as crop N needs and thus helped guide need-based fertilizer N top dressing for improving fertilizer N use efficiency in wheat. Fertilizer N management strategy based on application of prescriptive doses of 25 kg N ha^{-1} at planting and 45 kg N ha^{-1} at 1st irrigation and then a dose of 30 or 45 kg N ha^{-1} at 2nd irrigation stage depending on colour of the leaf to be ≥LCC 4 or <LCC 4 resulted in high yield levels as well as improved agronomic and recovery efficiencies of fertilizer N.

1. Introduction

Availability indices of soil nitrogen (N) are not very reliable (Nayyar et al., 2006) and it remains a challenge to estimate portion of soil N which can be taken up by crop plants. As soil N exists largely in organic forms, soil organic carbon status has been frequently used as an index for soil N supply (Pathak et al., 2003). However, kinetics of N release from soil organic matter and crop residues is very dynamic and the time and quantity of N supply from the soil always remain uncertain. The blanket fertilizer N recommendations for irrigated wheat established for large tracts consists of applying fixed fertilizer N doses at specified growth stages of the crop and do not consider field to field variability in soil N supply. Thus lack of synchronization in plant N demand and soil N supply leads to poor N use efficiency. Only 30–50% of the applied fertilizer N is used by the first crop (Ladha et al., 2005). Commonly followed practice of excessive fertilizer N applications to avoid the risk of N deficiency further reduces the use efficiency. Low recovery of N is not only responsible for high cost of crop production and increased insect-pest incidence but also for environmental degradation (Fageria and Baligar, 2005).

In-season N need in wheat can be estimated by using conventional tissue testing procedures (Roth et al., 1989; Yadava, 1986). Monitoring N status of a wheat tissue has advantages that plant integrates N supply over a period of time, and hence can reflect N supply as affected by weather, soil processing and fertilization. However, plant tissue analysis may require 1–2 weeks from tissue sampling to receiving a fertilizer recommendation and may not turn out to be a practically feasible proposition with large number of fields. The farmers generally use leaf colour as a visual and subjective indicator of the need for N fertilizer (Furuya, 1987). Since farmers generally prefer to keep leaves of the crop dark green, it

* Corresponding author. Tel.: +91 161 2401960x317; fax: +91 161 2400 945.
E-mail address: singhvp72@gmail.com (Varinderpal-Singh).

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leads to over application of fertilizers N resulting in low recovery efficiency. However, the spectral properties of leaves if used in a rational manner can lead to formulate need-based fertilizer N management strategies.

The leaf colour chart (LCC), an inexpensive and practically reliable diagnostic tool can be successfully used to guide need-based fertilizer N application in crops based on spectral properties of leaves. The strategies for using LCC for managing fertilizer N in rice and maize have already been established (Varinderpal-Singh et al., 2007, 2011), but for wheat these have not received adequate attention (Varinderpal-Singh et al., 2010). Shukla et al. (2004) found that application of fertilizer N to wheat when leaf colour was less than shade 4 on the LCC improved fertilizer N use efficiency. In Bangladesh, Alam et al. (2006) found LCC 4.5 as the critical value. Maiti and Das (2006) observed that threshold LCC 5 is better than LCC 4 for efficient N management in wheat in eastern India. These researchers applied LCC guided need-based fertilizer N top dressings at all the irrigation stages using single LCC threshold value. Gobinder Singh (2006), however, observed that using a single threshold value at all the growth stages did not work to improve agronomic and/or recovery efficiency of fertilizer N in wheat. Also, the fertilizer N applied along with irrigation events beyond maximum tillering stage may not help improve agronomic and recovery efficiency of fertilizer N. Thus, there was a need to conduct a systematic study to evaluate whether a single threshold LCC value can be used at all growth stages and to define the growth stage beyond which the applied fertilizer N did not improve agronomic and recovery efficiency of fertilizer N in wheat. We conducted six field experiments to understand (i) the relationship of leaf greenness as measured by LCC with leaf N concentration, chlorophyll meter (SPAD meter) readings and grain yield and (ii) to establish threshold LCC value for formulating a management strategy for need-based fertilizer N topdressings in wheat.

2. Materials and methods

2.1. Experimental site and soil characteristics

Experiments were conducted during 2005–2009 at Ludhiana (30°56′N, 75°52′E) in the research farm of the Punjab Agricultural University in fields with loamy sand to sandy loam surface soil texture and at Gurdaspur (32°03′N, 75°40′E) in the Regional Research Station of the Punjab Agricultural University in fields with silt loam surface soil texture. Both the sites are located in the Indo-Gangetic plains in the northwestern India. The climate of Ludhiana is subtropical with annual rainfall of 733 mm. The climate of Gurdaspur is sub-humid with annual rainfall of 887 mm. Mean maximum and minimum temperatures during the wheat growth season were respectively 35 °C and 18 °C at Ludhiana, and 27 °C and 18 °C at Gurdaspur. Some physico-chemical characteristics for the surface (0–0.15 m) soil samples collected and analyzed before sowing of wheat at different experimental sites are listed in Table 1.

2.2. Treatments and experimental design

A series of experiments with successive refinement in treatments were conducted during four years both at Ludhiana and Gurdaspur sites. The blanket recommendation dose of 120 kg N ha^{-1} applied in two equal split doses at planting and 1st irrigation and no-N control constituted the check treatments in all the experiments. The treatments in all the experiments were replicated thrice. The brief description of the objectives, varieties, experimental design and treatments of different experiments are given in Table 2.

Experiment 1 (2005–2006): The treatments were designed to work out the relationship between spectral properties of wheat leaf with leaf N concentration and grain yield. The fertilizer N was applied through urea in two equal split doses at planting and before the 1st irrigation event coinciding crown root initiation (CRI) stage of wheat.

Experiment 2 (2005–2006): The experiment was designed to evaluate LCC 4 and LCC 5 as threshold leaf colour shades for applying fertilizer N at 1st irrigation (CRI stage), 2nd irrigation (maximum tillering, MT stage) and 3rd irrigation (boot stage) in wheat cultivar *PBW 343*. The need-based fertilizer N (30 kg ha^{-1}) was top dressed at 1st, 2nd and 3rd irrigation stages if colour of the leaf was less green than the specified threshold. The threshold leaf greenness equal to the LCC shade 4 was evaluated with basal N dose of 30, 60 or 90 kg ha^{-1}, and threshold leaf greenness equal to the LCC shade 5 with basal N dose of only 30 kg ha^{-1}.

Experiment 3 (2006–2007): The LCC threshold shades 4 and 5 were evaluated but with basal N application doses more refined than in Experiment 2. After applying a basal N dose of 30, 45 and 60 kg ha^{-1}, the need-based topdressing of 30 kg N ha^{-1} were made at 1st, 2nd and 3rd irrigation stages if the leaf greenness of first fully exposed leaf was below the specified threshold. The threshold greenness of LCC 5 was also evaluated with no basal N dose.

Experiment 4 (2007–2008): As greenness of LCC shade 4 was found inadequate to guide need-based in-season fertilizer N topdressings in the Experiment 3, the usefulness of threshold greenness of LCC shade 5 was investigated in detail for guiding N application at 1st and 2nd irrigation stages. The experiment was conducted at both Ludhiana and Gurdaspur locations. There were five treatments consisting of basal N dose of 0, 30, 45 and 60 kg N ha^{-1} applied as urea and 25 kg N ha^{-1} applied as di-ammonium phosphate (DAP). The DAP was applied to wheat to supply 28 kg P ha^{-1} and along with it 25 kg N ha^{-1} gets applied. The treatments receiving basal N dose of 0–30 kg ha^{-1}, were given need-based fertilizer N topdressing of 30 or 45 kg ha^{-1} at 1st irrigation if the greenness of 1st fully exposed leaf was ≥LCC 5 or <LCC 5, followed by application of 30 kg N ha^{-1} if greenness of index leaf was <LCC 5 before the subsequent irrigation events. In the treatments with basal N dose of 45 kg ha^{-1} or more, need-based N top dressing of only 30 kg ha^{-1} was given before all the irrigation events. The need-based N management approach was evaluated both up to 2nd and 3rd irrigation event in all the treatments.

Experiment 5 (2007–2008): The experiment conducted at both Ludhiana and Gurdaspur sites was designed to test whether LCC should be used only once at 3rd irrigation stage or twice at 2nd and 3rd irrigation stages of wheat. Two treatments were based on threshold greenness of LCC 4 and LCC 5 to decide need-based N topdressing of 30 kg ha^{-1} at 2nd and 3rd irrigation after applying a basal dose of 30 kg N ha^{-1} and a dose of 45 kg N ha^{-1} at 1st irrigation. The other two treatments consisted of evaluating threshold greenness of LCC 4 and LCC 5 to guide need-based N topdressing of 30 kg ha^{-1} only at 3rd irrigation after the fixed N application of 30 kg ha^{-1} at planting and 45 kg ha^{-1} at 1st and 2nd irrigation.

Experiment 6 (2008–2009): The experiments were carried out both at Ludhiana and Gurdaspur sites with three sets of treatments consisting of basal N dose of 30 and 45 kg ha^{-1} as urea and 25 kg ha^{-1} as DAP. Each set consists of four treatments to evaluate threshold leaf greenness of LCC 4 and LCC 5 to guide need based fertilizer N topdressing at 2nd irrigation after applying a fixed N dose of 30 or 45 kg ha^{-1} at 1st irrigation.

2.3. Soil and crop management

Soil was ploughed after removing any residues from the previous crop and irrigated in the first week of October. After attaining field capacity, the land was ploughed twice to 20 cm depth, levelled

Table 1
Soil (0–0.15 m) properties of experimental sites during (2005–2009).

Experiment	Year	Sand ($g\,kg^{-1}$)	Silt ($g\,kg^{-1}$)	Clay ($g\,kg^{-1}$)	pH[¥]	EC[¶] ($dS\,m^{-1}$)	Organic carbon ($g\,kg^{-1}$)	Phosphorus[§] ($kg\,ha^{-1}$)	Potassium[#] ($kg\,ha^{-1}$)
Experiment 1[‡]	2005–06	795	167	38	7.46	0.15	4.7	12	109
Experiment 2[‡]	2005–06	795	167	38	7.46	0.15	4.7	12	109
Experiment 3[‡]	2006–07	790	177	33	7.50	0.12	4.0	18	72
Experiment 4									
Location – Ludhiana	2007–08	750	180	70	7.19	0.192	4.2	28	89
Location – Gurdaspur	2007–08	280	561	159	6.9	0.15	5.1	15	105
Experiment 5									
Location – Ludhiana	2007–08	782	170	48	7.0	0.29	4.4	15	93
Location – Gurdaspur	2007–08	280	561	159	6.9	0.15	5.1	15	105
Experiment 6									
Location – Ludhiana	2008–09	777	183	40	6.7	0.18	4.0	26	84
Location – Gurdaspur	2008–09	280	561	159	6.9	0.15	5.1	15	105

[¥] 1:2 soil/water.
[¶] Electrical conductivity.
[§] Sodium bicarbonate extractable.
[#] Ammonium acetate extractable.
[‡] Location – Ludhiana.

and divided in to plots not less than 30 m^2. Wheat was planted in 20 cm apart rows with a seed-cum-fertilizer drill. All P [28 kg P ha^{-1} as $Ca(H_2PO_4)_2$ or $(NH_4)_2HPO_4$ as per treatment] and K [25 kg K ha^{-1} as KCl] were drilled below the seed at sowing. The basal N dose was drilled in soil and top dressed fertilizer N was broadcasted just before the irrigation event to minimize N losses via ammonia volatilization (Katyal et al., 1987). The supply of nutrients other than nitrogen was ensured to be optimum. Four to five irrigations each of 7.5 cm were applied at crown root initiation stage, maximum tillering stage (MT), flowering/booting, and grain filling stages (depending upon rainfall events and climate) using groundwater and/or canal water. Crop was managed as per recommendations of the Punjab Agricultural University (Anonymous, 2004) and weeds, pests, and diseases were controlled as required. At maturity, wheat was harvested at ground level from an area of 7 m × 3 m in the centre of each plot. After sun drying grains were separated using a plot thresher, and weighed.

2.4. LCC and SPAD meter measurements

The six-panel leaf colour chart used in different experiments was manufactured by Nitrogen Parameters, Chennai, India as per specifications of International Rice Research Institute (IRRI, 1996). The SPAD meter used was the hand-held Minolta SPAD-502. It instantly provides an estimate of leaf N status as chlorophyll content by clamping the leafy tissue in the meter. The LCC was used to assess crop N need at different growth stages before the irrigation event starting from CRI stage to the initiation of flowering stage. Leaf colour and SPAD meter measurements were made from the first fully exposed leaf from top. The leaf was placed on top of the LCC and 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 shade of the body to avoid colour variance caused by direct sunlight. SPAD meter reading were recorded by inserting the middle portion of the index leaf in the slit of SPAD meter. Wet leaves, widely spaced, unusually tall or short plants were avoided. Every time the LCC and SPAD meter readings were recorded from randomly selected 15 plants in a plot.

2.5. Plant sampling

Leaves of wheat plants were sampled at different growth stages starting from CRI stage to the initiation of flowering stage of the crop. Fifteen index leaves from randomly selected plants of each treatment were collected at different crop growth stages for determination of N concentration. SPAD meter readings and LCC values of these leaves were recorded before sampling.

At maturity, grain and straw samples collected from each plot were dried in hot air oven at 65 °C and ground. Nitrogen concentration in leaf, grain and straw was determined by digesting the samples in H_2SO_4, followed by analysis for total N by a micro-Kjeldahl method (Yoshida et al., 1976).

2.6. Calculations and statistical analysis

The Cate-Nelson graphic method that helps to divide yield response in to high and low response region and thus define threshold level beyond which yield will suffer (Cate and Nelson, 1987) was used to establish threshold LCC value for guiding need-based N requirements of wheat at different growth stages. Average LCC scores at different growth stages were plotted against the relative grain yield (grain yield expressed as fraction of maximum grain yield) for the corresponding treatments. We took 0.91 relative grain yield as the horizontal critical level because treatment yields greater than that were not significantly different from the plateau yield at the 0.05 probability level. The vertical critical level was selected to minimize errors or outliers.

Data generated from experiments were analyzed following analysis of variance (ANOVA) using IRRISTAT version 5.0 (International Rice Research Institute, Philippines) and mean comparisons were performed based on least significant difference (LSD) test at 0.05 probability level. The coefficients of determination (R^2) were determined using MS EXCEL (Microsoft Corporation, Redland, CA, USA). The N-use efficiency measures – recovery efficiency (RE) and agronomic efficiency (AE) as described by Baligar et al. (2001) were computed as follows:

$$\mathrm{RE}\,(\%) = \frac{(\text{total N uptake in N fertilized plot} - \text{total N uptake in no N plot}) \times 100}{\text{quantity of N fertilizer applied in N fertilized plot}}$$

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

$$\mathrm{AE}\,(\text{kg grain/kg N applied}) = \frac{(\text{grain yield in N fertilized plot} - \text{grain yield in no N plot})}{\text{quantity of N fertilizer applied in N fertilized plot}}$$

Table 2
Description of the treatments of different experiments.

Experiment	Wheat genotype and statistical design	Treatments
Experiment 1	PBW 343, PBW 502 and PDW 274, split plot design with wheat genotypes in main plots and fertilizer N levels in the sub-plots	1. 0 kg N ha^{-1} 2. 40 kg N ha^{-1} 3. 80 kg N ha^{-1} 4. 120 kg N ha^{-1} 5. 160 kg N ha^{-1} 6. 200 kg N ha^{-1}
Experiment 2	PBW 343, randomized block design	1. No-N control 2. Blanket N application −120 kg N ha^{-1} 3. N_{30}[¥] basal + N_{30} if LG[¶] < LCC 4 at 1st, 2nd and 3rd irrigation 4. N_{60} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrigation 5. N_{90} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrigation 6. N_{30} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrigation
Experiment 3	PBW 343, randomized block design	1. No-N control 2. Blanket N application −120 kg N ha^{-1} 3. N_{30} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrigation 4. N_{45} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrigation 5. N_{60} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrigation 6. N_0 basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrigation 7. N_{30} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrigation 8. N_{45} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrigation 9. N_{60} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrigation
Experiment 4	PBW 343, randomized block design	1. No-N control 2. Blanket N application −120 kg N ha^{-1} 3. N_0 basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrigation + N_{30} if LG <LCC 5 at 2nd irrigation 4. N_0 basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrigation + N_{30} if LG <LCC 5 at 2nd and 3rd irrigation 5. N_{30} basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrigation + N_{30} if LG <LCC 5 at 2nd irrigation 6. N_{30} basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrigation + N_{30} if LG <LCC 5 at 2nd and 3rd irrigation 7. N_{45} basal + N_{30} if LG < LCC 5 at 1st and 2nd irrigation 8. N_{45} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrigation 9. N_{60} basal+ N_{30} if LG < LCC 5 at 1st and 2nd irrigation 10. N_{60} basal+ N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrigation 11. N_{25} basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrigation + N_{30} if LG <LCC 5 at 2nd irrigation 12. N_{25} basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrigation + N_{30} if LG <LCC 5 at 2nd and 3rd irrigation
Experiment 5	PBW 343, randomized block design	1. No-N control 2. Blanket N application −120 kg N ha^{-1} 3. N_{30} basal + N_{45} at 1st irrigation + N_{30} if LG < LCC 4 at 2nd and 3rd irrigation 4. N_{30} basal + N_{45} at 1st irrigation + N_{30} if LG < LCC 5 at 2nd and 3rd irrigation 5. N_{30} basal + N_{45} at 1st and 2nd irrigation + N_{30} if LG < LCC 4 at 3rd irrigation 6. N_{30} basal + N_{45} at 1st and 2nd irrigation + N_{30} if LG < LCC 5 at 3rd irrigation
Experiment 6	PBW 343, randomized block design	1. No-N control 2. Blanket N application −120 kg N ha^{-1} 3. N_{30} as basal + N_{30} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 4/< LCC 4 at 2nd irrigation 4. N_{30} as basal + N_{45} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 4/< LCC 4 at 2nd irrigation 5. N_{30} as basal + N_{30} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 2nd irrigation 6. N_{30} as basal + N_{45} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 2nd irrigation 7. N_{45} as basal + N_{30} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 4/< LCC 4 at 2nd irrigation 8. N_{45} as basal + N_{45} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 4/< LCC 4 at 2nd irrigation 9. N_{45} as basal + N_{30} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 2nd irrigation 10. N_{45} as basal + N_{45} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 2nd irrigation 11. N_{25} (as DAP) as basal + N_{30} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 4/< LCC 4 at 2nd irrigation 12. N_{25} (as DAP) as basal + N_{45} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 4/< LCC 4 at 2nd irrigation 13. N_{25} (as DAP) as basal + N_{30} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 2nd irrigation 14. N_{25} (as DAP) as basal + N_{45} at 1st irrigation + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 2nd irrigation

¥ Subscripts of N denote kg N ha^{-1}
¶ Leaf Greenness of first fully exposed leaf.

3. Results and discussion

3.1. Temporal changes and N effects on LCC readings

The colour of the topmost fully opened leaf of wheat plant as expressed in terms of LCC scores at different growth stages did not differ across the three genotypes – PBW 343, PBW 502 and PDW 274. Therefore, average LCC scores are plotted in Fig. 1 as a function of time and level of applied fertilizer N during the year 2005–06. The LCC scores of the wheat leaves increased with increasing fertilizer N level. In general, the leaf greenness increased from CRI to MT stage, irrespective of the levels of N application. Only exception was the no-N control where leaf colour showed a steep decline from CRI to MT stage, indicating that soil N supply was not sufficient to maintain green colour intensity of leaves. After the 2nd irrigation event at MT stage, the LCC score declined at boot stage in all the treatments. As shown in Fig. 2, which depicts changes in dry weight of index leaf with time, rapid vegetative growth during this phase increased N demand for chlorophyll synthesis and thus resulted in reduced LCC readings of the wheat leaves. Justes et al. (1997) reported decrease in N concentration as wheat plants grew from MT stage to boot stage due to dilution of N with structural

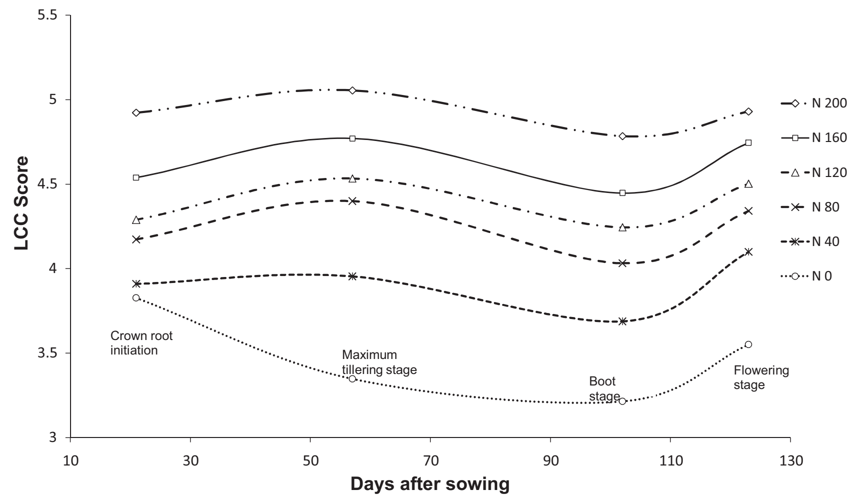

Fig. 1. Average leaf colour chart scores of the index leaf of three wheat genotypes at different growth stages as influenced by graded levels of fertilizer N application.

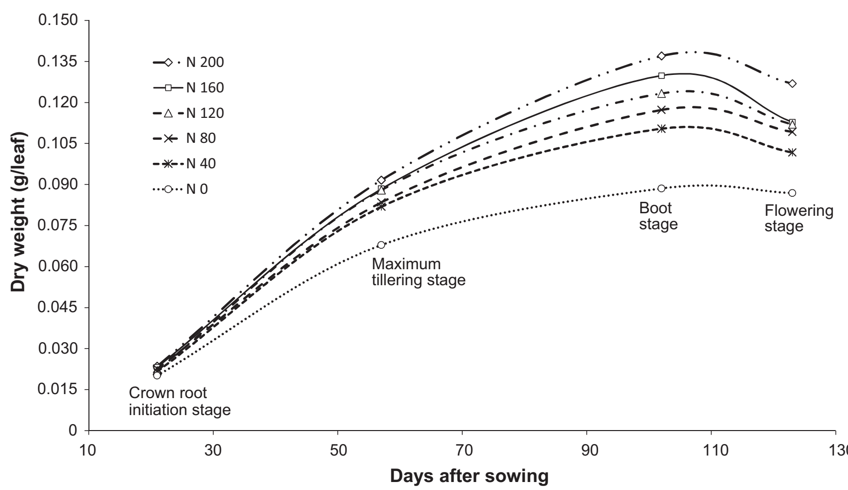

Fig. 2. Average leaf dry weight of the index leaf of three wheat genotypes at different growth stages as influenced by graded levels of fertilizer N application.

cellulose. Similar trend in SPAD values in wheat was reported by Debaeke et al. (2006). Nevertheless as the crop progressed from boot stage to flowering stage the LCC readings increased in all the treatments irrespective of the level of N application (Fig. 1) along with corresponding decrease in leaf weight (Fig. 2).

3.2. SPAD meter/LCC readings and leaf N concentration

A plot of SPAD meter readings versus LCC score across the genotypes and growth stages in Fig. 3 revealed a close linear relationship ($R^2 = 0.80$, $n = 108$). Since both gadgets consider leaf greenness as an indicator of leaf N concentration, the data in Fig. 3 suggest that LCC can be used as a reliable substitute of SPAD meter to guide need-based N applications in wheat. Shukla et al. (2004) and Win (2003) also observed significant relationship in LCC and SPAD meter readings in wheat. As depicted in Fig. 4 the LCC scores and leaf N concentration also showed significant coefficients of correlation at different growth stages. Since leaf colour chart score is closely related to leaf N concentration and SPAD meter readings across the wheat genotypes and crop growth stages it can be used as reliable indicator of indigenous N supply (INS) status of soil. The INS is defined as plant N accumulation in grain and straw at physiological maturity in no-N plots, and it represents contribution of all sources of N (soil, organic materials, crop residues, rhizosphere N fixation, irrigation water and rain fall) during the crop growing season (Dobermann et al., 2003). The LCC measures leaf colour as an indicator of leaf N concentration and considers N availavility from all these sources. Therefore use of LCC to predict leaf N concentration in wheat can help guide need-based fertilizer N applications

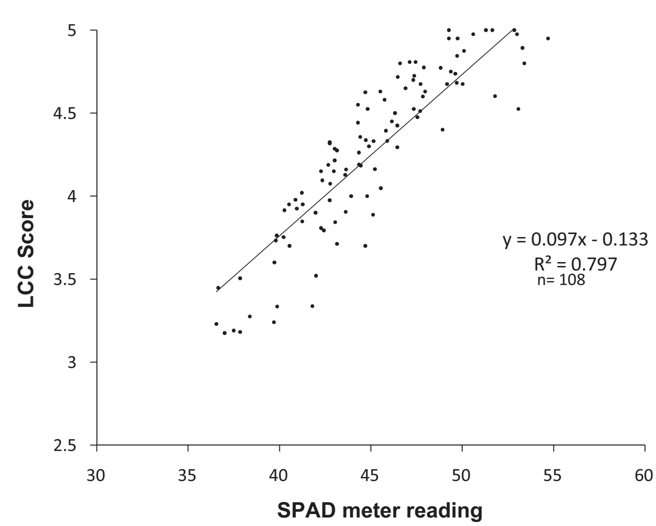

Fig. 3. Plot of LCC scores vs. SPAD meter readings at different growth stages of wheat.

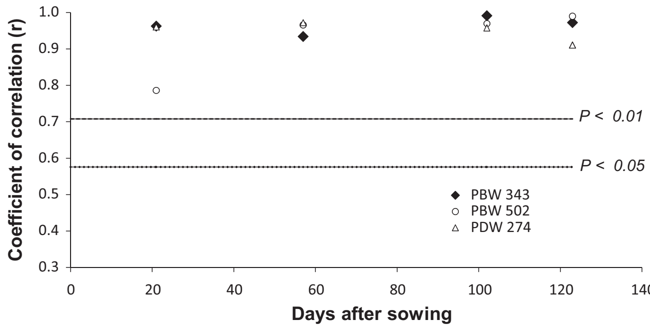

Fig. 4. Coefficients of correlation of LCC score with leaf nitrogen concentration at different growth stages in different wheat genotypes.

based on threshold LCC value. Moreover, direct relationship of LCC score with SPAD readings across the genotypes and crop growth stages provides confidence that single LCC threshold can be used as the critical LCC color for making need-based fertilizer N topdressing decisions in different wheat genotypes.

3.3. *Leaf colour chart measurements and wheat yield*

As shown in Fig. 5, the coefficients of correlation between grain yield at maturity and LCC scores at different growth stages (except CRI stage) varied from 0.95 to 0.99 and were statistically significant at $p < 0.01$. Small size of the leaves at CRI stage did not allow reliable leaf colour measurement and possibly was the reason for observing small coefficient of correlation at this stage. The coefficients of correlation between grain yield and LCC measurements at subsequent growth stages were very high (Fig. 5). It suggests that LCC can be successfully used as gadget to guide need-based fertilizer N application to obtain high fertilizer N use efficiency along with high yield level in wheat. Significant correlation in SPAD meter readings and wheat grain yield was observed by Reeves et al. (1993) and Murdock et al. (1997).

3.4. *Establishment of threshold LCC value and need-based fertilizer N management strategy*

The blanket fertilizer N recommendation for wheat over a vast area in the Indo-Gangetic plain consists of applying 120–150 kg fertilizer N ha^{-1} in two equal split doses – half at sowing and half at CRI (1st irrigation) stages. Blanket N recommendation does not take in to account the field-to-field variability in INS. The LCC measurement of the leaf greenness which has been calibrated with the SPAD meter should be able to take in to account both INS and temporal variability and lead to efficient management of N in real time.

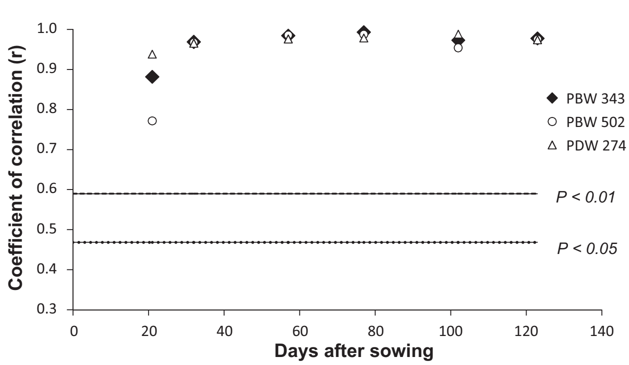

Fig. 5. Coefficients of correlation of LCC score with grain yield at different growth stages in different wheat genotypes.

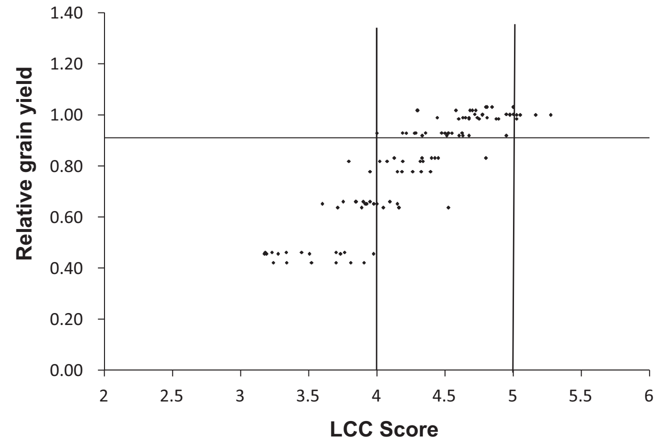

Fig. 6. Cate-Nelson graphic analysis relating LCC score of wheat leaves at different growth stages with relative grain yield.

The threshold LCC value refers to a leaf greenness below which the crop suffers from N deficiency resulting in yield loss. Maintaining leaf greenness at the threshold values simultaneously optimizes the grain yield, agronomic and recovery efficiencies of applied nitrogen. Data pertaining to different wheat genotypes at different growth stages as generated in Experiment 1 were pooled and Cate-Nelson plot of LCC scores against relative grain yield of 0.91 was made (Fig. 6) to establish threshold LCC values. The vertical critical level that indicates LCC threshold value was selected to minimize outliers and to ensure potential grain yield. The Cate-Nelson analysis did not work out any distinct threshold LCC value. It only provided an indication that leaf greenness between LCC 4 and LCC 5 may be appropriate to avoid N deficiency resulting in yield loss. As using a range of LCC shades as threshold may not be very practical, series of experiments were conducted to establish appropriate need-based N management strategy based on a single threshold LCC value in wheat.

The results of experiments conducted during 2005–2009 to establish need-based N management strategy are given in Tables 3–7. The data generated from the Experiment 2 conducted during the year 2005–2006 wheat season (Table 3) revealed that irrespective of basal N dose need-based fertilizer N topdressings using threshold LCC 4 always lead to grain yield lower than the blanket recommendation of 120 kg N ha^{-1}. Using threshold LCC shade 4 at all the growth stages did not allow fertilizer N application to match crop N need. It always resulted in less fertilizer N application. Using LCC shade 5 as threshold produced grain yield equivalent to that produced by blanket N dose of 120 kg ha^{-1} applied in two equal split doses. But this criterion ended up in application of fertilizer N similar to blanket recommendation but in four split doses.

Data from Experiment 3 conducted in 2006–2007 wheat season as listed in Table 4 confirmed that using LCC 4 as a threshold greenness of the fully opened top leaves of wheat plant for applying fertilizer N never resulted in the production of grain yield equivalent to that obtained by blanket fertilizer N recommendation of 120 kg N ha^{-1} applied in two split doses. Using threshold of LCC 4 resulted in application of only 45–60 kg N ha^{-1}. On the other hand, threshold LCC 5 guided need-based fertilizer N topdressings with basal N dose of at least 30 kg ha^{-1} produced grain yield equivalent to the blanket fertilizer N recommendation with the application of similar or higher amount of fertilizer N in three or four split doses. The LCC guided need-based fertilizer N topdressings using threshold LCC 5 without basal N dose lead to production of grain yield significantly lower than the blanket N application. The data for the two years indicated that LCC 4 cannot be used as appropriate threshold to guide need-based fertilizer N topdressings at all

Table 3
Total fertilizer N application, grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) of wheat in Experiment-2 during 2005–2006.

Treatment detail	Fertilizer N (kg ha^{-1})					Grain yield (t ha^{-1})	RE_N[§] (%)	AE_N[#]
	Basal	1st irrig.[†]	2nd irrig.	3rd irrig.	Total			
No-N control	0	0	0	0	0	2.43 a[¶]		
Blanket N application–120 kg N ha^{-1}	60	60	0	0	120	5.62 d	63.2 ab	26.6 a
N_{30}[¥] basal + N_{30} if LG[‡] < LCC 4 at 1st, 2nd and 3rd irrig.	30	0	30	30	90	4.70 c	59.8 ab	25.3 a
N_{60} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrig.	60	0	0	0	60	3.89 b	55.0 a	24.4 a
N_{90} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrig.	90	0	0	0	90	4.74 c	68.4 b	25.6 a
N_{30} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrig.	30	30	30	30	120	5.70 d	67.3 ab	27.2 a
LSD (p = 0.05)						0.793	11.68	5.79

¥ Subscripts of N denote kg N ha^{-1}.
¶ With in a column, means followed by same letter are not significantly different at the 0.05 level of probability.
§ Recovery efficiency of applied N.
# Agronomic efficiency (kg grain per kg applied N).
‡ Leaf Greenness of first fully exposed leaf.
† Irrigation.

the growth stages in wheat. The basal N dose was found necessary for obtaining the grain yield potential.

The treatments in Experiment 4 during 2007–2008 wheat season were designed keeping in view the observations that using threshold LCC shade 4 leads to lower grain yield. The data generated from Experiment 4 are listed in Table 5. At Ludhiana, wheat responded to fertilizer N application at 3rd irrigation only when no basal N was applied with grain yield production lower than the blanket N application. Threshold LCC 5 guided N topdressings at the time of 3rd irrigation suggested an application of another dose of 30 kg N ha^{-1} without any positive impact on grain yield in the treatments receiving a basal N application. Application of need-based fertilizer N up to 2nd irrigation stage with basal N dose of 25 kg ha^{-1} produced grain yield equivalent to blanket fertilizer N recommendation of 120 kg ha^{-1}. Applying a basal N dose of 30 or 45 kg ha^{-1} also produced equivalent grain yield with a saving of 15 kg N ha^{-1}. The data from the same set of treatments at Gurdaspur (Table 5) confirmed the conclusions that basal N dose of at least 25 kg N ha^{-1} should be applied for obtaining potential wheat grain yield and wheat respond to N application only up to 2nd irrigation (MT stage).

In the Experiment 5 conducted at Ludhiana and Gurdaspur during 2007–2008 season, LCC 4 or LCC 5 guided fertilizer N doses were top dressed at 2nd and 3rd irrigation stage or only at 3rd irrigation stage with fixed application of 45 kg N ha^{-1} at 1st or 1st and 2nd irrigation stage, respectively. Data reported in Table 6 confirmed the conclusions drawn in Experiments 1–4 that threshold LCC 5 guided N topdressing at 3rd irrigation leads to more N application without any improvement in grain yield. The wheat leaf colour was generally equal or greater than the greenness of LCC 4 and thus N topdressing at leaf greenness below LCC 4 lead to low N application if used at 2nd and 3rd irrigation stage.

The results from the experiments conducted during 2005–2008 revealed that (1) basal dose of at least 25 kg N ha^{-1} is required for the establishment of wheat (2) using LCC at 1st irrigation stage when leaves are too small is not practical and also due to very small N requirement at this stage, colour of the leaves is not guided by the basal N dose, (3) leaf greenness of fully exposed top leaf in wheat at 2nd irrigation stage is generally less than LCC shade 5 and equal to or more than LCC shade 4 (4) fertilizer N application at 3rd irrigation does not work to improve grain yield, and (5) the maximum grain yield with fertilizer N saving of 15–20 kg N ha^{-1} was obtained in treatments receiving 25 + 45 + 30, 30 + 45 + 30, 45 + 30 + 30 kg N ha^{-1} at planting, 1st irrigation and 2nd irrigation stages, respectively. In view of these observations, treatments in experiment 6 conducted during the year 2008–2009 were fine tuned and both LCC shades 4 and 5 were evaluated to guide adjustable (30 or 45 kg ha^{-1}) fertilizer N dose only at 2nd irrigation stage with fixed N application of 25, 30 or 45 kg ha^{-1} at planting and 30 or 45 kg ha^{-1} at 1st irrigation. The results as listed in Table 7 revealed that application of 30 (or 25) kg N ha^{-1} at planting and 30 kg N ha^{-1} at 1st irrigation as prescriptive doses did not work when LCC 4 guided need-based fertilizer N topdressings are to be made at 2nd irrigation stage of wheat. These treatments always resulted in low yield levels. Need based fertilizer N management at 2nd irrigation stage based on the criterion of leaf greenness ≥LCC 5

Table 4
Total fertilizer N application, grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) of wheat in Experiment-3 during 2006–2007.

Treatment detail	Fertilizer N (kg ha^{-1})					Grain yield (t ha^{-1})	RE_N[§] (%)	AE_N[#]
	Basal	1st irrig.[†]	2nd irrig.	3rd irrig.	Total			
No-N control	0	0	0	0	0	2.24 a[¶]	–	–
Blanket N application–120 kg N ha^{-1}	60	60	0	0	120	4.87 e	62.5 de	21.9 c
N_{30}[¥] basal + N_{30} if LG[‡] < LCC 4 at 1st, 2nd and 3rd irrig.	30	0	30	0	60	3.49 bc	56.9 bcd	20.8 bc
N_{45} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrig.	45	0	0	0	45	3.03 b	46.7 abc	17.5 abc
N_{60} basal + N_{30} if LG < LCC 4 at 1st, 2nd and 3rd irrig.	60	0	0	0	60	3.95 cd	73.2 e	28.5 d
N_0 basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrig.	0	30	30	30	90	3.46 bc	40.5 a	13.5 a
N_{30} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrig.	30	30	30	30	120	4.33 de	46.4 ab	17.4 abc
N_{45} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrig.	45	30	30	30	135	4.42 de	49.5 abcd	16.2 ab
N_{60} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrig.	60	0	30	30	120	4.26 d	46.6 abc	16.8 abc
LSD (p = 0.05)						0.58	13.56	5.45

¥ Subscripts of N denote kg N ha^{-1}.
¶ With in a column, means followed by same letter are not significantly different at the 0.05 level of probability.
§ Recovery efficiency of applied N.
# Agronomic efficiency (kg grain per kg applied N).
‡ Leaf Greenness of first fully exposed leaf.
† Irrigation.

Table 5
Total fertilizer N application, grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) of wheat in Experiment-4 during 2007–2008.

Treatment description	Fertilizer N (kg ha^{-1})					Ludhiana			Gurdaspur		
	Basal	1st irrig.[†]	2nd irrig.	3rd irrig.	Total	Grain yield (t ha^{-1})	RE_N[§] (%)	AE_N[#]	Grain yield (t ha^{-1})	RE_N[§] (%)	AE_N[#]
No-N control	0	0	0	0	0	1.73 a[¶]			2.28 a[¶]		
Blanket N application–120 kg N ha^{-1}	60	60	0	0	120	4.64 def	71.7 bc	24.3 bc	5.08 cd	59.7 abcde	23.4 cde
N_0[¥] basal + $N_{30/45}$ if LG[‡] ≥ LCC 5/< LCC 5 at 1st irrig. + N_{30} if LG < LCC 5 at 2nd irrig.	0	45	30	0	75	3.74 b	71.7 c	26.9 def	4.07 b	59.7 abcde	23.8 cde
N_0 basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrig. + N_{30} if LG < LCC 5 at 2nd and 3rd irrig.	0	45	30	30	105	4.34 c	70.3 abc	24.8 cde	4.3 b	55.8 abc	19.3 ab
N_{30} basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrig. + N_{30} if LG < LCC 5 at 2nd irrig.	30	45	30	0	105	4.61 def	68.9 abc	27.5 f	4.92 cd	61.6 cde	25.1 ef
N_{30} basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrig. + N_{30} if LG < LCC 5 at 2nd and 3rd irrig.	30	45	30	30	135	4.75 ef	64 a	22.4 abc	4.78 c	54.6 a	18.5 a
N_{45} basal + N_{30} if LG < LCC 5 at 1st and 2nd irrig.	45	30	30	0	105	4.58 cde	72.1 c	27.2 ef	4.93 cd	64.6 ef	25.2 ef
N_{45} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrig.	45	30	30	30	135	4.73 def	67.5 abc	22.2 ab	5.15 d	56.6 abcd	21.3 abcd
N_{60} basal + N_{30} if LG < LCC 5 at 1st and 2nd irrig.	60	30	30	0	120	4.67 def	71.1 abc	24.5 bcd	5.15 d	61.0 bcde	23.9 cde
N_{60} basal + N_{30} if LG < LCC 5 at 1st, 2nd and 3rd irrig.	60	30	30	30	150	4.84 f	65.3 ab	20.7 a	5.19 d	55.1 ab	19.4 ab
N_{25} basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrig. + N_{30} if LG < LCC 5 at 2nd irrig.	25	45	30	0	100	4.49 cd	73.2 c	27.6 f	5.05 cd	69.6 f	27.7 f
N_{25} basal + $N_{30/45}$ if LG ≥ LCC 5/< LCC 5 at 1st irrig. + N_{30} if LG < LCC 5 at 2nd and 3rd irrig.	25	45	30	30	130	4.66 def	68.9 abc	22.6 abc	4.99 cd	62.7 de	20.8 abc
LSD ($p = 0.05$)						0.24	7.50	2.48	0.317	6.23	3.07

¥ Subscripts of N denote kg N ha^{-1}.
¶ With in a column, means followed by same letter are not significantly different at the 0.05 level of probability.
§ Recovery efficiency of applied N.
# Agronomic efficiency (kg grain per kg applied N).
‡ Leaf Greenness of first fully exposed leaf.
† Irrigation.

Table 6
Total fertilizer N application, grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) of wheat in Experiment-5 during 2007–2008.

Treatment description	Fertilizer N (kg ha^{-1})					Ludhiana			Gurdaspur		
	Basal	1st irrig.[†]	2nd irrig.	3rd irrig.	Total	Grain yield (t ha^{-1})	RE_N[§] (%)	AE_N[#]	Grain yield (t ha^{-1})	RE_N[§] (%)	AE_N[#]
No-N control	0	0	0	0	0	1.32 a[¶]			2.21 a[¶]		
Blanket N application–120 kg N ha^{-1}	60	60	0	0	120	4.34 c	67.4 a	25.1 b	5.14 c	71.9 a	24.4 ab
N_{30}[¥] basal + N_{45} at 1st irrig. + N_{30} if LG[‡] < LCC 4 at 2nd and 3rd irrig.	30	45	0	0	75	3.49 b	72.8 a	28.9 c	4.42 b	79.4 a	29.4 c
N_{30} basal + N_{45} at 1st irrig. + N_{30} if LG < LCC 5 at 2nd and 3rd irrig.	30	45	30	30	135	4.42 c	70.8 a	23 ab	5.62 d	71.7 a	25.2 ab
N_{30} basal + N_{45} at 1st and 2nd irrig. + N_{30} if LG < LCC 4 at 3rd irrig.	30	45	45	0	120	4.36 c	72.6 a	25.3 b	5.55 d	78.9 a	27.8 bc
N_{30} basal + N_{45} at 1st and 2nd irrig. + N_{30} if LG < LCC 5 at 3rd irrig.	30	45	45	30	150	4.46 c	70.5 a	21 a	5.62 d	67.3 a	22.7 a
LSD ($p = 0.05$)						0.276	7.06	2.34	0.404	NS	3.45

¥ Subscripts of N denote kg N ha^{-1}.
¶ With in a column, means followed by same letter are not significantly different at the 0.05 level of probability.
§ Recovery efficiency of applied N.
\# Agronomic efficiency (kg grain per kg applied N).
‡ Leaf Greenness of first fully exposed leaf.
† Irrigation.

or <LCC 5 always leads to application of 45 kg N ha^{-1}. While there was hardly any yield advantage of applying this dose, it always led to application of higher total fertilizer N dose as compared to when criterion of leaf greenness ≥LCC 4 or <LCC 4 was used to apply 30 or 45 kg N ha^{-1}, respectively. Thus using a prescriptive dose of 25 kg N ha^{-1} at planting and 45 kg N ha^{-1} at 1st irrigation and then applying a need-based dose of 30 or 45 kg N ha^{-1} at 2nd irrigation stage depending on colour of the leaf to be ≥LCC 4 or <LCC 4 not only led to high grain yields but also higher fertilizer N use efficiencies when compared to application of blanket dose of 120 kg N ha^{-1}. This criterion very well takes care of N supplying capacity of the soil as well as N needs of the crop depending upon its yield potential and can be used for efficient fertilizer N management in wheat.

Synchronizing crop N demand with fertilizer N supply using LCC based N management strategy lead to AE and RE of applied N as high as 29.2 kg grain per kg applied N and 79.3%, respectively. Improved AE and RE of applied N support the observations of Dobermann et al. (2004) who regarded AE exceeding 25 kg grain per kg applied N and RE exceeding 60% with high grain yields as efficient N management strategies for timely sown wheat. Bijay-Singh et al. (2002) reported wheat response to need based fertilizer N application at MT stage. The data suggest that increased fertilizer N use efficiency at optimum yield levels was observed due to lower rates of total N application (as compared to blanket recommendations) when appropriate prescriptive fertilizer N applications are combined with a LCC guided fertilizer N application at 2nd irrigation stage. The LCC based N applications in wheat reduces nitrous oxide gas emission up to the extent of 18% in comparison to the blanket N application at fixed growth stages (Bhatia et al., 2011). The inability of blanket fixed-time split N applications at specified growth stages to synchronize N supply with actual crop N demand because of poorly designed N splitting and variations in crop N demand and INS was also noticed by Ladha et al. (2000).

Shukla et al. (2004) used LCC shade 4 as threshold greenness for guiding fertilizer N applications at each of the four irrigation events. Improved fertilizer N use efficiency was observed even with no basal N dose. Results in the present investigation do not support the observation of growing wheat with no basal N dose. Also no response of wheat was observed to N application after 2nd irrigation when wheat enters flowering stage. Nitrogen uptake of irrigated wheat proceeds very slowly until tillering begins, and N flux (kg N ha^{-1} day^{-1}) increases to a maximum around Feekes 6 stage (Doerge et al., 1991) which coincides with maximum tillering stage at 2nd irrigation (Bijay-Singh et al., 2011). In a study carried out on irrigated wheat in 10 countries, it was found that N recovery in wheat improves with fertilizer N application at Feekes 6 stage (IAEA, 2000).

Alam et al. (2006) showed the usefulness of LCC shade 4.5 guided fertilizer N topdressing at 2nd irrigation (MT stage) in wheat. Using LCC shade 4.5 may not be very practical for the farmers. The experiments carried out in the present study at field locations with loamy sand, sandy loam and silt loam soil textures revealed that LCC shade 4 is an appropriate threshold greenness to guide application of fertilizer N dose at 2nd irrigation stage. The need based N management strategy evolved in the present investigation should be applicable in soils with wide range of textures. Even in coarse texture soils as found in Ludhiana, there exists substantial evidence from ^{15}N labelled fertilizer that leaching and denitrification losses are minimal in irrigated wheat (Katyal et al., 1987). Losses via ammonia volatilization can be substantial from urea but these can be checked to a large extent by applying urea-N immediately before applying irrigation. It results in transport of urea-N to sub surface soil layer from where NH_3 cannot escape (Katyal et al., 1987).

Table 7
Total fertilizer N application, grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) of wheat in Experiment-6 during 2008–2009.

Treatment description	Fertilizer N (kg ha^{-1})				Ludhiana			Gurdaspur		
	Basal	1st irrig.†	2nd irrig.	Total	Grain yield (t ha^{-1})	RE_N§ (%)	AE_N#	Grain yield (t ha^{-1})	RE_N§ (%)	AE_N#
No-N control	0	0	0	0	2.3 a¶			2.04 a¶		
Blanket N application–120 kg N ha^{-1}	60	60	0	120	4.5 de	47.6 a	18.4 a	4.81 def	58.8 a	23.1 bcd
N_{30}¥ as basal + N_{30} at 1st irrig. + $N_{30/45}$ if LG‡ ≥ LCC 4/ < LCC 4 at 2nd irrig.	30	30	30	90	4.21 bc	57.7 bcd	21.5 cd	4.24 b	67.5 de	24.5 e
N_{30} as basal + N_{45} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 4/ < LCC 4 at 2nd irrig.	30	45	30	105	4.62 def	61.1 d	22.1 d	4.92 fg	72.9 f	27.4 f
N_{30} as basal + N_{30} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 5/ < LCC 5 at 2nd irrig.	30	30	45	105	4.6 def	59.2 cd	21.9 d	4.81 def	73.6 f	26.3 f
N_{30} as basal + N_{45} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 5/ < LCC 5 at 2nd irrig.	30	45	45	120	4.59 def	53.8 abc	19.1 ab	4.81 def	65.5 cd	23.1 bcd
N_{45} as basal + N_{30} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 4/ < LCC 4 at 2nd irrig.	45	30	30	105	4.63 def	61.6 d	22.2 d	4.87 efg	74.5 f	27.0 f
N_{45} as basal + N_{45} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 4/ < LCC 4 at 2nd irrig.	45	45	30	120	4.85 f	57.5 bcd	21.3 bcd	4.8 def	64.3 cd	23.0 bc
N_{45} as basal + N_{30} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 5/ < LCC 5 at 2nd irrig.	45	30	45	120	4.56 de	52.4 abc	18.8 a	4.7 d	63.1 bc	22.2 b
N_{45} as basal + N 45 at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 5/ < LCC 5 at 2nd irrig.	45	45	45	135	4.7 ef	51.6 ab	17.8 a	4.75 de	59.1 ab	20.1 a
N_{25} (as DAP) as basal + N_{30} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 4/ < LCC 4 at 2nd irrig.	25	30	30	85	4.12 b	56.2 bcd	21.4 bcd	4.31 bc	70.7 ef	26.7 f
N_{25} (as DAP) as basal + N_{45} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 4/ < LCC 4 at 2nd irrig.	25	45	30	100	4.42 cd	61.9 d	21.2 bcd	4.96 g	79.3 g	29.2 g
N_{25} (as DAP) as basal + N_{30} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 5/ < LCC 5 at 2nd irrig.	25	30	45	100	4.2 bc	55.6 bcd	19.4 abc	4.42 c	67.9 de	23.8 cde
N_{25} (as DAP) as basal + N_{45} at 1st irrig. + $N_{30/45}$ if LG ≥ LCC 5/ < LCC 5 at 2nd irrig.	25	45	45	115	4.75 ef	57.4 bcd	21.3 bcd	4.83 defg	67.7 de	24.3 de
LSD ($p = 0.05$)					0.276	7.08	2.33	0.137	3.98	1.20

¥ Subscripts of N denote kg N ha^{-1}.
¶ With in a column, means followed by same letter are not significantly different at the 0.05 level of probability.
§ Recovery efficiency of applied N.
# Agronomic efficiency (kg grain per kg applied N).
‡ Leaf Greenness of first fully exposed leaf.
† Irrigation.

4. Conclusions

The farmers practice of applying blanket N doses at fixed growth stages does not take care of spatial and temporal variability in soil N supply and is not adequate for obtaining high agronomic and recovery efficiencies of fertilizer N in wheat. Leaf colour chart, a simple and cost effective gadget can now be used in wheat to guide in-season fertilizer N application as per crop need. Matching fertilizer N supply with crop N demand using threshold LCC shade 4 to guide whether 30 or 45 kg N ha^{-1} is to be applied at 2nd irrigation after application of prescriptive dose of 25 kg N ha^{-1} at planting and 45 kg N ha $^{-1}$ at 1st irrigation can ensure high yield levels and improved agronomic and recovery efficiencies of applied fertilizer N. To improve fertilizer N use efficiencies in irrigated wheat the blanket recommendation of applying fixed N dose at fixed growth stages over a large tract should be gradually replaced with need-based fertilizer N management.

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