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Calibrating the leaf colour chart for need based fertilizer nitrogen management in different maize (*Zea mays* L.) genotypes

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ABSTRACT

Large field to field variability restricts efficient fertilizer N management when broad based blanket recommendations are used in maize (*Zea mays* L.). To achieve higher yields and to avoid nitrogen (N) deficiency risks, many farmers apply fertilizer N in excess of crop requirement in maize. Field experiments were conducted for five years (2005–2009) to establish and evaluate threshold leaf colour to guide in-season need based fertilizer N topdressings in four maize genotypes. Colour (of the first top maize leaf with fully exposed collar) as measured by comparison with different shades of green colour on a leaf colour chart (LCC) and maize grain yield was significantly correlated. The Cate–Nelson plot of chlorophyll (SPAD) meter/leaf colour chart values against relative grain yield of 0.93 for the experiments conducted during first two years indicated that LCC shade 5 during vegetative growth stages and LCC shade 5.5 at silking stage (R1) can guide crop demand driven N applications in maize. Evaluation of the established threshold leaf greenness during the next three years revealed that fertilizer N management using LCC 5 starting from six-leaf (V6) stage to before R1 stage resulted in improved agronomic and N recovery efficiency in different maize genotypes. There was no response to fertilizer N application at R1 stage. The study revealed that in maize, fertilizer N can be more efficiently managed by applying fertilizer N dose based on leaf colour as measured by LCC than blanket recommendation.

1. Introduction

Fertilizer nitrogen (N) has become the key input in food production. Cereals including rice, wheat, and maize account for more than half of the total fertilizer N consumption in the world. As per estimates 50–70% more cereal grain will be required by 2050 to feed over 9 billion world population. This will further increase demand for fertilizer N at greater magnitude unless the fertilizer N recovery efficiency in cereals is improved. It is only 30–50% by the first crop and not more than 7% by the six consecutive crops (Ladha et al., 2005). The remaining N is lost from the soil–plant system. The generally followed practice of excessive fertilizer N applications to avoid the risk of N deficiency further reduces this efficiency. Excessive N application causes nutrient imbalances and produces plants that are disease- and pest-susceptible. Low recovery of N is not only responsible for higher cost of crop production, but also for environmental pollution (Fageria and Baligar, 2005).

Blanket recommendations based on fixed-time application of fertilizer N doses at specified growth stages do not consider the dynamic soil N supply and crop N requirements, and lead to untimely application of fertilizer N. Therefore, demand driven need based fertilizer N management in maize can help to improve N recovery efficiency and to reduce N losses. In-season N requirement of maize can be accomplished using conventional tissue testing procedures. Monitoring N status of a maize tissue and seasonal N availability 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 takes 10–14 days from tissue sampling to receiving a fertilizer recommendation and does not seem to be a practical proposition. 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 leads to over application of fertilizers N resulting in low recovery efficiency. Thus, the spectral properties of leaves should be used in a more rational manner to guide need based fertilizer N applications.

The concept of using spectral reflectance ratio to quantify colour of intact crop leaves was reported in the early sixties in Japan (Inada, 1963). It was only in the late eighties and early nineties that researchers (Furuya, 1987; Jund and Turner, 1990; Peng et al., 1993) focused on using gadgets such as leaf colour chart (LCC) (based on spectral properties of leaves) and chlorophyll meter (SPAD meter) (based on light transmittance through leaves) for guiding real-time N top dressings in rice. These gadgets helped efficient N manage-

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ment in rice and wheat under situations encountering diversity in field, season and variety by ensuring high yields, and providing economic benefits to the farmers, but the technology for their use in maize has not been well established.

Significant correlations have been observed between chlorophyll content index values obtained with chlorophyll meter and foliar or whole plant N in maize (Bullock and Anderson, 1998). Peterson et al. (1993) reported the potential of need based fertilizer N management technology using SPAD meter in maize and SPAD meter was found as helpful guide to regulate the timing of N application (Vetsch and Randall, 2004). Defining a critical SPAD value and to apply N as and when SPAD value fell below the critical limit is the criterion for using chlorophyll meter (Zebarth et al., 2002). For example, in transplanted rice, a SPAD value of 35 was found to be the appropriate threshold for guiding need-based N management (Peng et al., 1996). Several researchers (Peng et al., 1993; Murdock et al., 1997; Turner and Jund, 1991; Yang et al., 2003; Shukla et al., 2004) have also reported significant coefficients of correlation between grain yield and N concentration in leaves or SPAD values recorded at critical physiological growth stages in rice and wheat. Nevertheless, the SPAD meter threshold value may vary among varieties, hybrids and environmental conditions (Varinderpal-Singh et al., 2010) and is not examined for maize in Asian countries. SPAD meter is an efficient tool but being relatively expensive may not be owned by small and marginal farmers individually.

Inexpensive and practically reliable alternative to the SPAD meter is the use of LCC. It has been successfully used for regulating N supply to rice and wheat (Shukla et al., 2004; Varinderpal-Singh et al., 2007; Yadvinder-Singh et al., 2007). The LCC shade 4 on the six-panel IRRI-LCC has been found to be the threshold score for transplanted coarse grain rice varieties prevalent in the Indo-Gangetic plains (Bijay-Singh et al., 2002; Hussain et al., 2003). Being a simple and cost-effective gadget it has already penetrated into South Asian farming and increasing numbers of farmers are finding it helpful in efficiently managing N fertilizer in rice and there is a need to establish technology for its use in maize.

The present investigation was carried out during 2005 to 2009 with four maize genotypes and includes two kinds of experiments. In the first category of experiments conducted during 2005 and 2006, the objective was to study the relationship of leaf greenness as measured by LCC with leaf N concentration, SPAD meter readings and grain yield and to find out threshold LCC value for guiding crop demand driven need based fertilizer N applications in different maize genotypes. In the second category, the experiments were conducted during next three years so as to validate the critical LCC threshold value and to evaluate the LCC based fertilizer N applications vis-à-vis blanket fixed time fertilizer N management in improving N recovery efficiency in maize.

2. Materials and methods

2.1. Experimental site and soil characteristics

Field experiments were conducted for five years during 2005 to 2009 on a Typic Ustipsamment (Fatehpur loamy sand) at the research farm of the Punjab Agricultural University, Ludhiana (30°56′ N, 75°52′ E), located in the northwestern India. The region receives an average 730 mm yr^{-1} rainfall, about 80% of which occurs from June to September. Mean maximum and minimum temperatures are, respectively, 35 and 18 °C during the year. Soil pH, electrical conductivity, organic carbon, phosphorus and potassium content in surface (0–0.15 m) soil layer of the experimental sites ranged from 7.2 to 7.6, 0.14 to 0.22 ds m^{-1}, 4.1 to 4.6 g kg^{-1}, 11 to 38 kg ha^{-1} and 108 to 140 kg ha^{-1}, respectively.

2.2. Treatments and experimental design

Two categories of experiments were carried out with four maize genotypes—*Parbhat* (long duration composite variety), *F9572A* (short duration hybrid), *PMH1* (long duration hybrid) *and 30V92* (long duration hybrid). The treatments in both the categories of experiments were laid out in a split plot design with three replications. Maize genotypes were kept in main plots. The sub-plots consisted of fertilizer treatments.

2.2.1. Experiment 1

In the experiments conducted during 2005 and 2006, the sub-plot treatments consisted of fertilizer N levels of 0, 60, 90, 120, 150, 180 and 210 kg N ha^{-1} applied through urea in three equal splits at planting, knee high and pre-tasseling stage in maize genotypes *PMH1* and *F9572A*.

2.2.2. Experiment 2

During 2007–2009, the need based N management options using LCC were evaluated in comparison with fixed time fertilizer N application in the four maize genotypes. After the application of 30 kg N ha^{-1} at sowing, the need based N management options using LCC threshold 5 and 5.5 [from six-leaf stage (V6) to before silking stage (R1)] were evaluated with and without application of fertilizer N at R1 stage using LCC threshold 5.5 and 6, respectively. At V6 stage sixth leaf (from bottom) of the maize plant fully emerges with a collar visible at the leaf base, but the collar of the leaf seven is not yet visible. At R1 stage crop enters reproductive phase and silking appears on the cobs. In-season need based fertilizer N topdressings of 30 kg N ha^{-1} were applied (with irrigation/rainfall) whenever leaf greenness was less than the specified threshold. Fixed time fertilizer N application treatments include application of 120 and 150 kg N ha^{-1} in three equal splits at sowing, knee high and pre-tasseling stage. The control treatment receiving no-fertilizer N was also maintained.

2.3. Soil and crop management

Soil was ploughed after removing any residues from the previous wheat crop and irrigated in the first week of May. After attaining field capacity, the land was ploughed twice to 20 cm depth, leveled and divided in to plots not less than 27 square meters in different years. Phosphorus (26 kg P ha^{-1} as single superphosphate) and potassium (25 kg K ha^{-1} as muriate of potash) were drilled below the seed at sowing of maize. Four to five irrigations were given to ensure adequate soil moisture throughout the crop season. Crop was managed as per recommendations of Punjab Agricultural University (Anonymous, 2004). Weeds, pests and diseases were controlled as and when required.

At maturity, grain and stover yields were determined from an area of 7 m × 3 m in the center of each plot. Maize stalks were harvested along with cobs by hand at ground level. After manual picking and sun drying of cobs, grains were separated using a plot thresher, and weighed. Grain and stover moisture content was determined in sub-samples after drying to constant weight in oven at 65 °C for 48 h. Grain weight was expressed at 140 g kg^{-1} water content. Stover weight was expressed on an oven dry weight basis.

2.4. LCC/SPAD meter measurements

Six-panel leaf colour chart used in this study was manufactured by N Parameters, Chennai, India as per specifications of International Rice Research Institute (IRRI, 1996). It consisted of high quality plastic with strips of green colour shades of increasing green colour intensity from 1 to 6. SPAD meter used is 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 and SPAD meter were used to assess crop N need at 7–10 day interval starting from V6 to R1 stage (Peterson et al., 1993). Before the tasseling stage measurements were made from the first leaf with fully exposed collar from top. After the tasseling stage, the ear leaf was used as index leaf (Peterson et al., 1993). The topmost fully expanded 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 ruler. During measurement, the leaf being measured was kept under shade of the body to avoid colour variance caused by sun's angle and sunlight intensity. 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. To minimize the spillover effect the sampling was done to obtain 15 readings from randomly selected plant leaves in a plot.

2.5. Plant sampling

Leaves of maize plants were sampled at different growth stages starting from V6 stage to R1 stage of the crop. Fifteen index leaves from randomly selected plants of each treatment were collected at different crop growth stages of maize for determination of N concentration. SPAD meter readings and LCC values of these leaves were recorded before sampling.

At maturity grain and stover samples collected from each plot were dried in hot air oven at 70 °C and ground to pass through a 0.5 mm sieve. Grain yield (14% moisture) and stover yield (oven dry) were recorded. Nitrogen concentration in leaf, grain and stover 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). Nitrogen in grain and stover was taken as a measure of total N uptake.

2.6. Calculations and analysis

The Cate–Nelson graphic method (Cate and Nelson, 1987) was used to establish threshold LCC value for guiding need based N requirements of maize genotypes 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 0.93 relative grain yield as the horizontal critical level because treatment yields greater than that were not significantly different from the plateau yield at the 0.10 probability level. The vertical critical level was selected to minimize errors or outliers.

Data generated from the two 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:

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

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

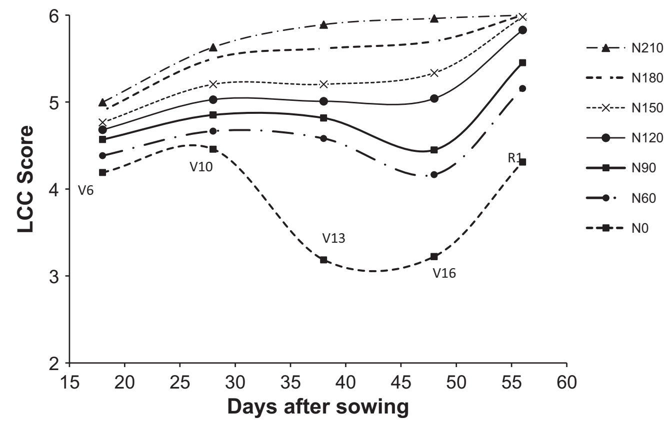

Fig. 1. Average leaf colour chart scores of two maize genotypes as influenced by N application rate at different growth stages.

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

3. Results and discussion

3.1. Experiment 1

3.1.1. Temporal changes and N effects on LCC readings

LCC scores of the *PMH1* and *F9572A* maize genotypes for the year 2005 and 2006 as a function of time and level of applied fertilizer N are shown in Fig. 1. Both genotypes exhibited similar trends with increasing fertilizer N levels. The LCC scores of the maize leaves were in complete accord with fertilizer N level. In general, LCC readings increased during the early growth stage from V6 to V10 (10-leaf stage), irrespective of the levels of N application. Indigenous sources and applied basal N dose continued to supply N for chlorophyll synthesis and thus green colour intensity of the leaves increased during early phase of the crop growth even in the no-N plot. After V10 stage of the crop, steep decline in LCC readings was observed in no-N control whereas LCC readings in other treatments were only slightly influenced till V13 stage followed by a decline in treatments receiving 60 and 90 kg N ha^{-1}. In the treatments receiving 120 to 210 kg N ha^{-1}, LCC readings up to V16 stage (16-leaf stage) of the crop remain unchanged. Rapid vegetative growth (Fig. 2) during the V10–V16 stages and increasing demand of N for chlorophyll synthesis resulted in a decline in LCC readings of the maize leaves in low N treatments. But as the crop entered

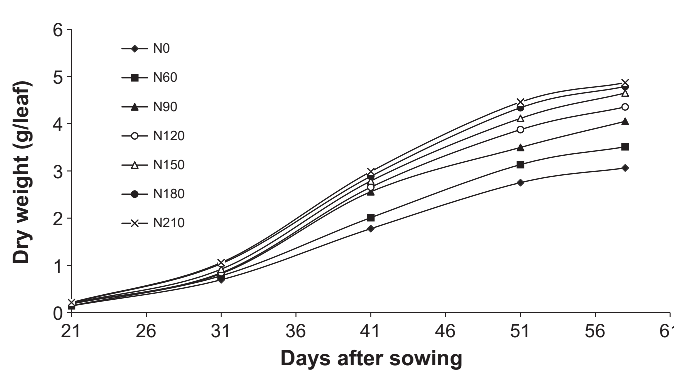

Fig. 2. Average leaf dry weight of the index leaf of two maize genotypes at different growth stages as influenced by graded levels of fertilizer N application.

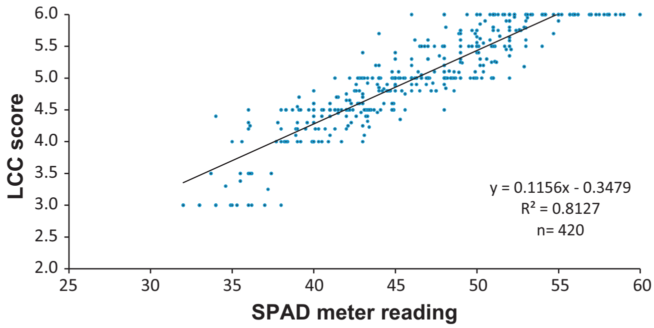

Fig. 3. Plot of LCC scores *versus* SPAD meter readings at different growth stages of maize.

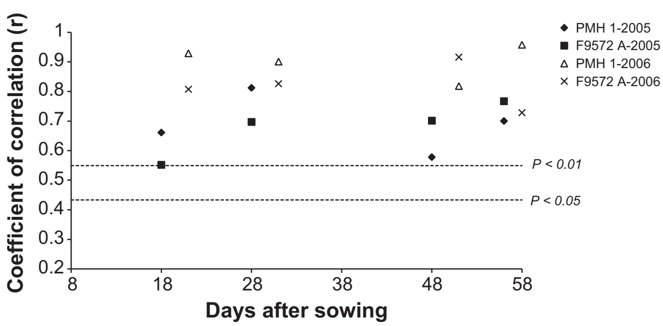

Fig. 4. Coefficient of correlation of LCC score with leaf nitrogen concentration at different growth stages in two maize genotypes.

reproductive phase (R1) the LCC readings increased in all the treatments irrespective of the level of N application. This increase is attributed to the change in index leaf from topmost fully exposed leaf to ear leaf at this stage.

3.1.2. SPAD meter/LCC readings and leaf N concentration

A plot of SPAD meter readings *versus* LCC score across the genotypes and growth stages shows a close linear relation in Fig. 3 ($R^2 = 0.813$, $n = 420$). 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 an inexpensive substitute of SPAD meter to guide need based N applications in maize. The LCC scores and leaf N concentration at different growth stages were significantly correlated during both the years (Fig. 4). Thus LCC could reliably predict N concentration in maize leaves and help guide need based fertilizer N applications by establishing threshold LCC values for different genotypes.

3.1.3. Leaf colour chart measurements and maize yield

The LCC scores at different growth stages of maize and grain yield at maturity were significantly correlated ($P < 0.01$) for both the genotypes (Fig. 5). The coefficient of correlation increased with advancement in crop growth stage. It suggests that during early stages of maize there was sufficient N supply from soil as well as from basal N application. Blackmer et al. (1993) observed better relationship ($r = 0.81$) between SPAD meter readings and maize yield at the later growth stages R4 (dough stage) and R5 (dent stage) than that at V6 stage. Piekielek et al. (1995) found a correlation of 0.84 for the relationship between relative SPAD meter readings and relative grain yield of maize. In the present investigation we obtained the correlation of 0.84–0.90 between grain yield and LCC scores at R1 growth stage of different maize varieties in different years. It proves that LCC can be successfully used as gadget to guide need based fertilizer N application to obtain high yield level.

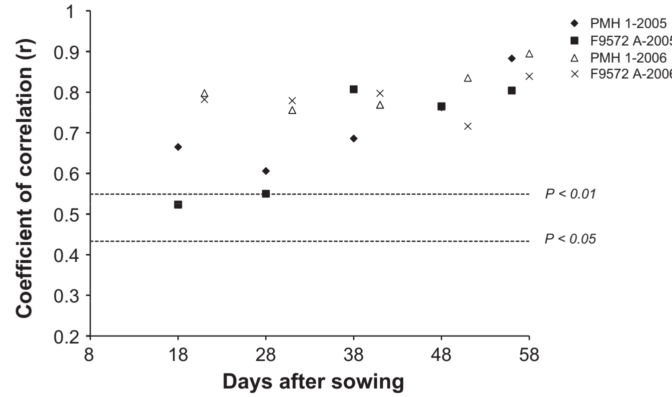

Fig. 5. Coefficient of correlation of grain yield with LCC score at different growth stages in two maize genotypes.

3.1.4. Establishment of threshold LCC values

Threshold LCC value is defined as the LCC reading corresponding to a leaf greenness below which the crop suffers from N deficiency resulting in yield loss. Variations in LCC readings during vegetative and reproductive stages (Fig. 1) indicate the need of establishing LCC thresholds for both vegetative and reproductive growth stages. Argenta et al. (2004) and Spectrum Technologies Inc. (1998) also observed different threshold SPAD values for different growth stages in maize. Data for vegetative growth stages and early reproductive stage were pooled separately, and Cate–Nelson plot of LCC scores against relative grain yield of 0.93 was prepared (Fig. 6) to establish threshold values for vegetative and reproductive growth stages. The relative grain yield 0.93 was used as horizontal critical level because yields greater than this level were not significantly different from the plateau yield at the 0.10 probability level. The vertical critical level that indicates LCC threshold value was selected to minimize outliers and to ensure potential grain yield. Threshold value, below which the crop would suffer from N deficiency resulting in yield loss, was observed to be LCC shade 5, during vegetative growth stages. Higher LCC value of 5.5 is required at R1 stage to obtain a relative grain yield of 0.93.

3.2. Experiment 2

3.2.1. Validation of threshold LCC values

Results from experiments conducted to evaluate different need based N management strategies during 2007 to 2009 are listed in Tables 1–3. The results obtained with maize varieties *Parbhat* and *F9572A* during the year 2007 indicated that using LCC threshold 5.5 lead to application of 30 kg N ha^{-1} more than using LCC threshold 5 during vegetative growth stages without any yield benefit (Table 1). Agronomic and recovery efficiency of fertilizer N were also decreased when fertilizer N was managed using LCC threshold 5. There was no response to fertilizer N application at R1 stage in both the treatments. Using LCC at R1 stage resulted in application of additional 30 kg N ha^{-1} without any yield benefit and thus resulted in reduced agronomic and recovery efficiencies. The LCC threshold 5 guided fertilizer N applications of 90 kg N ha^{-1} (during vegetative growth stages) produced grain yield comparable with fixed time application of 150 kg N ha^{-1} with 20.8–22.8% higher fertilizer N recovery efficiency and 8.3–8.5 kg higher grain yield production per kg fertilizer N (Table 1). Comparable grain yield with 30 kg N ha^{-1} less fertilizer N was attributed to tailoring of the timings of fertilizer N applications (Table 4). Blanket applications at fixed growth stages were not able to match fertilizer N supply with plant N demand and thus produced yield comparable with need based N management strategy only if 30 kg or more fertilizer N was applied at fixed growth stages.

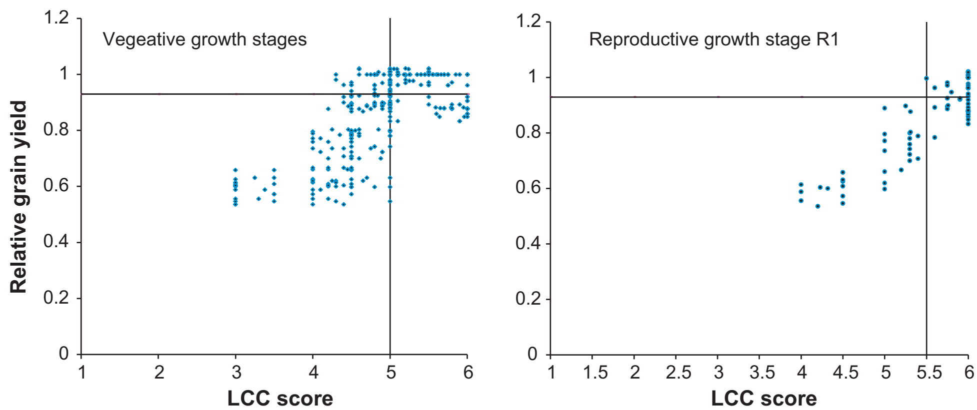

Fig. 6. Cate–Nelson graphic analysis relating LCC score of maize leaves at vegetative and reproductive growth stages with relative grain yield.

Table 1
Total fertilizer N application, grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) of maize varieties during 2007.

Treatment detail	Total fertilizer N application	Grain yield (t ha^{-1})		RE_N		AE_N	
		cv. *Parbhat*	cv. *F9572A*	cv. *Parbhat*	cv. *F9572A*	cv. *Parbhat*	cv. *F9572A*
No-N control	0	2.30a[¶]	2.44a	–	–	–	–
120 kg N ha^{-1} in three equal splits[a]	120	4.03b	4.30b	40.9a	40.5a	14.4a	15.4abc
150 kg N ha^{-1} in three equal splits[a]	150	4.20b	4.31b	40.1a	38.7a	12.7a	12.4a
Need based—LCC < 5[b] (V6 to before R1 stage[c])	90	4.19b	4.32b	60.9d	61.5d	21.0b	20.9d
Need based—LCC < 5.5[b] (V6 to before R1 stage[c])	120	4.14b	4.21b	48.8bc	47.3bc	15.3a	14.7abc
Need based—LCC < 5[b] (V6 to before R1 stage) and LCC < 5.5 (at R1 stage)	120	4.22b	4.39b	51.0c	49.8c	16.0a	16.2bc
Need based—LCC < 5.5[b] (V6 to before R1 stage) and LCC < 6 (at R1 stage)	150	4.30b	4.40b	44.9ab	42.7ab	13.3a	13.0ab
LSD (0.05)	Variety	0.08		1.9		1.1	
	Treatment	0.20		4.2		2.5	
	Variety × Treatment	0.28		5.9		3.5	

[a] At sowing, knee-high and pre-tasseling stages.
[b] Fertilizer N application was made whenever LCC score was below specified threshold. A basal dose of 30 kg N ha^{-1} was applied in all need based N application treatments.
[c] V6—six-leaf stage, R1—silking stage.
[¶] With in a column, means followed by same letter are not significantly different at the 0.05 level of probability

Evaluation of different need based fertilizer N management strategies during the year 2008 in maize varieties *PMH1* and *Parbhat* confirmed the usefulness of LCC 5 as threshold during vegetative growth stages for improving fertilizer N recovery efficiency and for obtaining high yields. It was observed that there was no response to fertilizer N application at R1 stage following different LCC threshold values. Using LCC 5.5 as threshold during vegetative growth stages produced grain yield equivalent to the management option

Table 2
Total fertilizer N application, grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) of maize varieties grown during 2008.

Treatment detail	Total fertilizer N application	Grain yield (t ha^{-1})		RE_N		AE_N	
		cv. *PMH1*	cv. *Parbhat*	cv. *PMH1*	cv. *Parbhat*	cv. *PMH1*	cv. *Parbhat*
No-N control	0	2.40a[¶]	2.14a	–	–	–	–
120 kg N ha^{-1} in three equal splits[a]	120	4.19b	3.98b	44.3a	42.5a	14.9ab	15.3a
150 kg N ha^{-1} in three equal splits[a]	150	4.23b	4.22b	42.1a	44.0a	12.2a	13.9a
Need based—LCC < 5[b] (V6 to before R1 stage[c])	90	4.27b	4.03b	64.9d	63.8c	20.7c	21.0b
Need based—LCC < 5.5[b] (V6 to before R1 stage)	120	4.23b	4.20b	49.7abc	52.4ab	15.3ab	17.2a
Need based—LCC < 5[b] (V6 to before R1 stage) and LCC < 5.5 (at R1 stage)	120	4.31b	4.17b	55.7bcd	55.1bc	16.0b	16.9a
Need based—LCC < 5.5[b] (V6 to before R1 stage) and LCC < 6 (at R1 stage)	150	4.28b	4.27b	46.8ab	48.6ab	12.6ab	14.2a
LSD (0.05)	Variety	0.08		3.2		1.2	
	Treatment	0.20		7.1		2.6	
	Variety × Treatment	0.28		10		3.7	

[a] At sowing, knee-high and pre-tasseling stages.
[b] Fertilizer N application was made whenever LCC score was below specified threshold. A basal dose of 30 kg N ha^{-1} was applied in all need based N application treatments.
[c] V6—six-leaf stage, R1—silking stage.
[¶] With in a column, means followed by same letter are not significantly different at the 0.05 level of probability.

Table 3
Total fertilizer N application, grain yield, recovery efficiency of nitrogen (RE_N) and agronomic efficiency of nitrogen (AE_N) of maize varieties grown during 2009.

Treatment detail	Total fertilizer N application	Grain yield (t ha^{-1})		RE_N		AE_N	
		cv. *PMH1*	cv. *30V92*	cv. *PMH1*	cv. *30V92*	cv. *PMH1*	cv. *30V92*
No-N control	0	3.40a[¶]	5.43a	–	–	–	–
120 kg N ha^{-1} in three equal splits[a]	120	4.96b	6.52b	36.4a	27.9a	13.0a	9.1a
150 kg N ha^{-1} in three equal splits[a]	150	5.20b	6.47b	39.7a	32.2a	12.0a	6.9a
Need based—LCC < 5[b] (V6 to before R1 stage[c])	60	5.15b	6.59b	77.8b	66.1b	29.2c	19.2c
Need based—LCC < 5.5[b] (V6 to before R1 stage)	120	5.10b	6.55b	37.8a	39.3a	14.2ab	9.3ab
Need based—LCC < 5[b] (V6 to before R1 stage) and LCC < 5.5 (at R1 stage)	90	5.04b	6.50b	49.1a	45.9a	18.2b	11.8b
Need based—LCC < 5.5[b] (V6 to before R1 stage) and LCC < 6 (at R1 stage)	150	5.15b	6.50b	35.0a	28.1a	11.7a	7.1a
LSD (0.05) Variety		0.07		6.4		1.1	
Treatment		0.17		14.3		2.4	
Variety × Treatment		0.24		20.2		3.3	

[a] At sowing, knee-high and pre-tasseling stages.
[b] Fertilizer N application was made whenever LCC score was below specified threshold. A basal dose of 30 kg N ha^{-1} was applied in all need based N application treatments.
[c] V6—six-leaf stage, R1—silking stage.
[¶] With in a column, means followed by same letter are not significantly different at the 0.05 level of probability.

using LCC5 as threshold, however, guided higher fertilizer N applications. Using LCC 5 as threshold lead to the production of grain yield equivalent to that produced with fixed time application of 150 kg N ha^{-1} but with the application of only 90 kg N ha^{-1}. Recovery efficiency was increased by 19.8–22.8 along with grain yield production improvement by 7.1–8.5 kg grain per kg applied fertilizer N (Table 2).

The LCC guided fertilizer N management technology was evaluated in maize varieties *PMH1* and *30V92* during the year 2009. The crop performance and yields during this year were better than during the year 2007 and 2008. This can be observed from fast growth of the crop during initial vegetative phase. The crop attained knee high stage about a week earlier than in the previous years (Table 4). This rapid and better growth was attributed to sowing of crop well before the onset of monsoon season that facilitates germination and growth during the initial stages. The surface 0–0.15 m soil sample of the field was also high in organic carbon, phosphorus and potassium status (Table 5) that further supported better and rapid growth during this year.

The grain yields in no-N control treatment were higher for both the varieties during 2009 than in the previous years. The data indicate that N supply from the soil during 2009 was higher than in the other fields during the previous years. Interestingly, need based N management using LCC threshold 5 considered this spatial variability and lead to application of only 60 kg N ha^{-1} during 2009 which was otherwise 90 kg N ha^{-1} during the previous years. The grain yield produced with LCC threshold 5 guided application of 60 kg N ha^{-1} was equivalent to that produced with fixed time application of 150 kg N ha^{-1}. The data established the usefulness of LCC guided N management in improving agronomic and N recovery efficiency. Recovery efficiency of fertilizer N was improved by 33.9–38.1% with improvement in grain yield production by 12.3–17.2 kg grain per kg applied fertilizer N (Table 3). Using LCC at R1 stage leads to application of 30–90 kg N ha^{-1} more than the LCC threshold 5 guided N management during vegetative growth stages without any yield benefit or improvement in agronomic and fertilizer N recovery efficiency. It was found that need based application of 30 kg N ha^{-1} whenever (starting from V6 stage to before R1 stage)

Table 4
Treatments used and rate and time of fertilizer N application in different maize varieties during 2007–2009.

Treatment details	N rate (kg ha^{-1}) at each split	Time of N application (days after sowing)					
		2007[a]		2008[b]		2009[c]	
		Var. *Parbhat*	Var. *F9572A*	Var. *PMH1*	Var. *Parbhat*	Var. *PMH1*	Var. *30V92*
No-N control	0	–	–	–	–	–	–
120 kg N ha^{-1}[d]	40	0, 33, 48	0, 33, 48	0, 36, 50	0, 36, 50	0, 28, 49	0, 28, 49
150 kg N ha^{-1}[d]	50	0, 33, 48	0, 33, 48	0, 36, 50	0, 36, 50	0, 28, 49	0, 28, 49
Need based N application at LCC < 5[e] (from V6 to before R1[f])	30	0, 21, 43	0, 21, 43	0, 21, 42	0, 21, 42	0, 21	0, 21
Need based N application at LCC < 5.5[e] (from V6 to before R1)	30	0, 21, 33, 43	0, 21, 33, 43	0, 21, 31, 42	0, 21, 31, 42	0, 21, 33, 44	0, 21, 33, 44
Need based N application at LCC < 5[e] (from V6 to before R1) and at <5.5 (at R1)	30	0, 21, 43, 58	0, 21, 43, 58	0, 21, 42, 58	0, 21, 42, 58	0, 21, 60	0, 21, 60
Need based N application at LCC < 5.5[e] (from V6 to before R1) and at <6 (at R1)	30	0, 21, 33, 43, 58	0, 21, 33, 43, 58	0, 21, 31, 42, 58	0, 21, 31, 42, 58	0, 21, 33, 44, 60	0, 21, 33, 44, 60

[a] Date of sowing—June 20, 2007.
[b] Date of sowing—June 6, 2008.
[c] Date of sowing—May 27, 2009.
[d] At sowing, knee-high and pre-tasseling stage.
[e] Fertilizer N application was made whenever LCC score was below specified threshold. A basal dose of 30 kg N ha^{-1} was applied in all need based N application treatments.
[f] V6—six-leaf stage, R1—silking stage.

Table 5
Soil (0–0.15 m) properties of experimental sites during (2005–2009).

Year	Sand (g kg^{-1})	Clay (g kg^{-1})	pH[a]	EC[b] (dS m^{-1})	Organic carbon (g kg^{-1})	Phosphorus[c] (kg ha^{-1})	Potassium[d] (kg ha^{-1})
2005	670	112	7.2	0.15	4.4	22	134
2006	670	112	7.2	0.15	4.4	22	134
2007	692	105	7.3	0.22	4.1	11	108
2008	692	105	7.3	0.22	4.1	11	108
2009	652	122	7.6	0.14	4.6	38	140

[a] 1:2 soil/water.
[b] Electrical conductivity.
[c] Sodium bicarbonate extractable.
[d] Ammonium acetate extractable.

leaf greenness is less than LCC threshold value 5 is the appropriate need based fertilizer N management strategy along with a basal dose of 30 kg N ha^{-1}.

4. Conclusions

The generally followed blanket recommendation of applying fixed N dose at fixed time intervals is not adequate for obtaining high agronomic and recovery efficiency of fertilizer N in maize. Matching fertilizer N supply with crop demand using threshold LCC shade 5 saved 25–50% fertilizer N. This study provides evidence for the usefulness of LCC guided need based fertilizer N management technology in assuring high yields and improvement in fertilizer N recovery efficiency. LCC being a cost effective, simple and farmer's friendly gadget can be easily used even by small and illiterate farmers. Thus the blanket recommendations of applying fixed N dose at fixed time intervals should be replaced with need based fertilizer N management technology using LCC in maize.

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