

Optimization of nitrogenous fertilizers using leaf-colour chart for irrigated hybrid maize (*Zea mays*) grown in *Vertisol* of sub-tropical India

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ABSTRACT

A field experiment was conducted at Raichur, Karnataka, India, during the rainy seasons of 2016 and 2017, to study the response of hybrid maize leaf-colour chart (LCC) to N and evaluate threshold to enhance crop yields, N-use efficiency (NUE) by altering splits as per crop need guided by LCC. Treatments included LCC thresholds of 1, 2, 3, 3.5, 4, 4.5, 5 and 6 compared with fixed splits at definite growth stages and absolute control. Application of 30 kg N/ha, whenever greenness of first fully opened leaf from the top was less than shade of the thresholds on the LCC. Hybrid maize showed significant response to application of N up to 120 kg N/ha in 3 equal split doses. Beyond this level, fertilizer NUE was significantly reduced. The LCC ≤ 5 proved better than other LCC shades for guiding real-time N management and achieving higher NUE. Application of 80–110 kg N/ha using threshold LCC ≤ 4.5 inclusive of 62.5 kg N/ha basal resulted in higher grain yield of maize which was at par with the application of 150 kg N/ha applied in 3 equal split doses.

Key words: Leaf colour chart, LCC thresholds, Maize, Nitrogen-use efficiency, Vertisols

Improving fertilizer nitrogen-use efficiency (NUE) in maize is vital to achieve and sustain high crop yields and reduce N losses. N-fertilizers are expensive input, but farmers tend to apply in large amounts to minimize the risk of deficiency intended to achieve higher crop yields. Efficiency of applied N generally declines with increased fertilizer use, and seldom exceeds 40% (Dass *et al.*, 2015a). Nitrogen requirement of maize can vary greatly across fields, seasons and growing years because of high variability among fields, in-season soil N-supplying capacity (Dobermann *et al.*, 2003; Dass *et al.*, 2014, Ghosh *et al.*, 2017; Ghosh and Dass, 2019) as well as differences in climatic factors (Kropff *et al.*, 1993). In recent years, maize hybrids of short-duration and higher yield potentials are being developed to replace the conventional inbred cultivars. Requirement of N of these maize hybrids is expected to be different from that of inbred. Therefore, to enhance NUE in the hybrid maize it is necessary to know the actual amounts of N required and the right time of its application. The real time N management approach can help to avoid application of excessive amount of N fertilizer at fixed in-

tervals by matching time of application with plant need (Ghosh *et al.*, 2017; Dass *et al.*, 2015b).

The guidelines evolved using tools including leaf colour chart (LCC), can help to apply crop demand-driven site-specific N applications and result in high productivity with profits. The need-based N management in hybrid maize using leaf-colour chart (LCC) has the potential to replace the blanket uniform fertilizer rates recommended across Vertisol. It has already been found very useful in efficient management of fertilizer N in inbred maize cultivars (Singh *et al.* 2002; Singh *et al.* 2011) in Indo-Gangetic alluvial soils. Objectives of the present study were to optimize LCC threshold and to manage N according to LCC to achieve higher NUE and productivity in hybrid maize. Approaches were application of fertilizer N at fixed critical growth stages and need-based N management using LCC to achieve synchrony between crop needs and supply.

MATERIALS AND METHODS

The field experiment was conducted in the rainy season of 2016 and 2017 at Main Agricultural Research Station of the University of Agricultural Sciences, Raichur (16.6°N, 77.3°E, 329.6 m). The soil of the experiment field was clay loam in texture, having pH 8.42. Under average climatic conditions, the area receives 770 mm of mean annual rain-

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fall, about 80% of which occurs from July to September. Rainfall received during the maize-growing season (August to November) was 433 mm and 639 mm during 2016 and 2017 respectively. The mean monthly temperature during the maize-growing seasons was 24 to 34 °C.

The field experiment was laid out in a randomized block design, replicated thrice. The treatments included LCC 1, LCC \leq 2, 3, 4, 4.5, 5, 5.5 and 6 thresholds compared with regional N recommendation of 150 kg N/ha in 3 splits and absolute control (without application of N fertilizers). The colour of the fully expanded leaf from the top was compared with LCC panel in every 10–12 days interval, starting from 21 days after sowing (DAS). Nitrogenous fertilizer was applied @ 30 kg/ha every time when leaf colour was less green than LCC pre-fixed threshold. Need-based fertilizer N applications were made up to 75 DAS. Time and amount of N fertilizers applied during the two years are presented in Table 1. Urea and diammonium ammonium phosphate were selected as source of N fertilizers.

Field preparation included disc ploughing in relatively dry soil during the first week of July followed by harrowing to make soil fine tilth. Maize hybrid ‘NK 6240’ was sown at 0.6 m rows and 0.2 m intra-row spacing on 20 July 2016 and 9 August 2017. Plot size was 7.2 m \times 4.0 m and final harvest grain yield was estimated from 15.36 m². Crop was grown under assured irrigation without water stress throughout crop period. At each irrigation, 3 to 5 cm depth of canal water was applied, and irrigation interval depended on the rainfall and surface soil moisture. All the treatment plots received uniform dose of 75 kg P₂O₅/ha, 37.5 kg K₂O/ha and 10 kg ZnSO₄/ha. Whole of the P, K and Zn were applied basal. Fertilizer N in fixed N dose treatment was applied in 3 equal splits at basal, 30 and 55 DAS just before irrigation event to minimize N losses. Crop was managed as per the regional recommendations of the UAS,

Raichur. Weeds, pests and diseases were managed as and when required throughout the growing season.

The 6-panel leaf-colour chart used in the experiment was manufactured by nitrogen parameters, Chennai, India as per the specifications of the PAU, Ludhiana, India. The threshold LCC value refers to leaf greenness below which the crop suffers from N deficiency results in yield loss. Maintaining leaf greenness at the threshold values simultaneously optimizes the grain yield, agronomic and partial factor productivity of applied N. The LCC was used to assess crop N need at different growth stages at 10–12 days interval before irrigation events starting from 3 weeks after planting up to 75 days. Readings of LCC were recorded from 3rd top most leaves. The leaf was placed on top of the LCC panel and colour of the middle part of the leaf was matched according to the corresponding colour strip on the LCC. During each measurement, the leaf being measured was kept under shade of the body to avoid colour variance caused by direct sunlight. For each plot randomly selected 20 plants used for measurement. During all the observations single person recorded LCC readings to avoid personal bias and to achieve greater uniformity.

Plant samples from second row from border on both sides harvested for dry-matter estimation at regular intervals. At maturity, maize plants were manually harvested plot-wise for yield estimation in the first week of November. A sub-sample of grain and straw was collected for determining moisture content. Yield attributes were estimated from 5 plants harvested from net plot area. Grain yield was expressed based on 10% water content and straw yield was expressed on sundry-weight basis. Grain and straw samples were dried in hot air oven at 65°C and ground for total N content estimation by a micro-Kjeldahl method. Uptake of N was calculated by multiplying grain yield and straw yield by N content. Recovery and agronomic efficiency of added

Table 1. Quantity of nitrogen fertilizers applied for different treatments under different LCC thresholds and regional recommendation during 2016 and 2017

Treatment	Basal*	Time of N application		Total N (kg/ha)		Saving of fertilizers over RDN (%)	
		(kg/ha)		2016	2017	2016	2017
		2016	2017				
LCC threshold \leq 1	62.5			62.5	62.5	67	58
LCC threshold \leq 2	62.5			62.5	62.5	67	58
LCC threshold \leq 3	62.5	20,66	23	122.5	92.5	36	38
LCC threshold \leq 3.5	62.5	20,29	23	122.5	92.5	36	38
LCC threshold \leq 4	62.5	20,55	23,55	122.5	122.5	36	18
LCC threshold \leq 4.5	62.5	20,41	23,41,55	122.5	152.5	20	-2
LCC threshold \leq 5	62.5	20,41	23,29,41,66	122.5	182.5	4	-22
LCC threshold \leq 6	62.5	20,29,41,55,66,75	23, 29, 41, 55,66	242.5	212.5	-28	-42
150 kg N/ha	75	29,55,66	23, 41, 55	150	150		
N ₀	0	-	-	0	0		

*Common basal dose in both 2016 and 2017; RDN, recommended dose of nitrogen

N were calculated with following relationship as described by Baligar *et al.* (2001) and Cassman *et al.* (1998).

$$REN = \frac{N \text{ uptake in fertilized plot (kg/ha)} - N \text{ uptake in no-N plot (kg/ha)}}{\text{Fertilizer N applied (kg/ha)}}$$

$$AEN = \frac{\text{Grain yield in N fertilized plot (kg/ha)} - \text{Grain yield in no-N plot (kg/ha)}}{\text{Fertilizer N applied (kg/ha)}}$$

Data from the experiment were analysed following analysis of variance (ANOVA) using Statistical Analysis Systems (SAS) software (Version 9.3, SAS Institute, Inc., Cary, NC, USA). Replicate was identified to be unique within each year and rep × year was considered random. Regression analysis across sampling dates was also conducted in SAS 9.3 using the PROC REG procedure. Least significance difference (LSD) at 0.05 level of probability (P=0.05) was used to test the significance. Graphs were created in Sigma Plot 12.5 software (SPSS Inc., Chicago IL) by nonlinear curve fitting procedures. For validation of the prediction model, root mean square error (RMSE %) was used to test the goodness of fit between the predicted and observed yields from an independent data collected from field experiment.

$$RMSE (\%) = \sqrt{1/n \sum_{i=1}^n (x_i - y_i)^2} \times 100/y$$

where x_i , y_i , y and n represent observed values, predicted values, mean of the observed values and number of samples respectively.

RESULTS AND DISCUSSION

Temporal leaf-colour chart LCC scores

Colour of topmost leaves expressed in terms of LCC readings varied at all the growth stages of maize. Average of 20 leaves recorded at different growth stages in 2016 and 2017 is plotted in Fig. 1a and 1b respectively. In general, LCC readings increased with the increase in crop age and LCC threshold 3–6. These readings peaked at 50–55 DAS, thereafter decreased in both 2016 and 2017 except in LCC 1 and LCC ≤ 2. Lowest LCC values were recorded throughout the season in absolute control wherein no N was applied. However, lower LCC scores were increased with higher N application as growth advanced based on LCC ≤ 4 to LCC ≤ 6. During early crop stage lower LCC values were not recovered by N application but LCC 1, ≤ 2 and ≤ 3. Soil-nitrogen sufficiency indicated by leaf greenness was not achieved in less than LCC 3 thresholds. Frequent top-dressing-based on LCC ≤ 4 to ≤ 6 has resulted higher LCC score indicated more leaf greenness in both the years. At 21 DAS there was no significant difference in LCC readings among recommended dose of nitrogen (RDN), LCC-based N-applied treatments indicated that

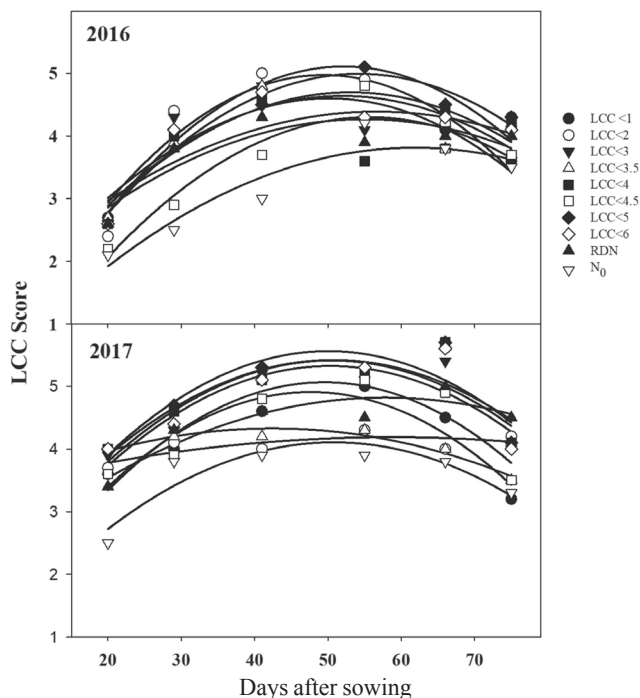


Fig. 1. Leaf colour chart scores recorded in hybrid maize at different growth intervals in 2016 and 2017 at Raichur, Karnataka

basal N application had no effect on N absorption and uniform native N status. Singh *et al.* (2002) reported no significant difference in grain yield of rice between 20 kg N/ha and without basal N under LCC-based N management. Singh *et al.* (2012) reported that, LCC scores in wheat were influenced by LCC-based N application rate (0 to 200 kg N/ha) but not with genotypes. Further, N concentration in leaf decreased as crop progressed. The Cute–Nelson analysis provided an indication that leaf greenness between LCC 4, 5 and 6 may be appropriate to avoid N deficiency resulted yield loss.

Grain yield and LCC scores

Application of N fertilizers based on LCC ≤ 4.5, LCC ≤ 5 and LCC ≤ 6 thresholds increased the grain yield by 3.9, 17.9 and 16.2%, respectively, over 150 kg N/ha at fixed intervals pooled over 2 years (Fig. 2). Yield potential also varied between 2016 and 2017 due to variation in rainfall. Further increase in N rate beyond LCC ≤ 5 thresholds did not cause significant improvement in the grain yield of maize. Greater grain yield improvement was observed by application of N based on N threshold as compared to the control without N application except LCC1. The grain yield of hybrid maize was statistically on par with N application based on LCC threshold ≤ 4.5 to ≤ 6.0. Though fertilizer N using LCC threshold 5 restricted in significantly higher grain yield, yields were like that achieved with LCC ≤ 4.5 in both the years. It indicated that maize grown in

Vertisol LCC ≤ 4.5 (122.5 kg N/ha) was found to be optimum instead of N application at fixed intervals. The results of our study also agree with the findings of Mathukia *et al.* (2014), who reported that N applied based on either LCC ≤ 4 and LCC ≤ 5 has significantly improved grain yield of maize in Gujarat clayey soils, wherein LCC ≤ 4 -based N application enhanced grain yield up to 21% over 80 kg N/ha at fixed intervals. It also indicated by relationship between LCC-based N application and grain yield ($r^2 = 0.85^{**}$) and stalk yield ($r^2 = 0.71^{**}$) (Fig. 3). Similar magnitude of yield improvement was also reported by Singh *et al.* (2011) and Gajera *et al.* (2014). In Indo-Gangetic plain, Singh *et al.* (2007) found that, LCC ≤ 4 with a basal dose of 20 kg N/ha can be used for efficient N management in maize cultivars. Shantappa *et al.* (2014) reported that, N applied in rice-based LCC ≤ 5 saved 30 kg N/ha without significant reduction in grain yield.

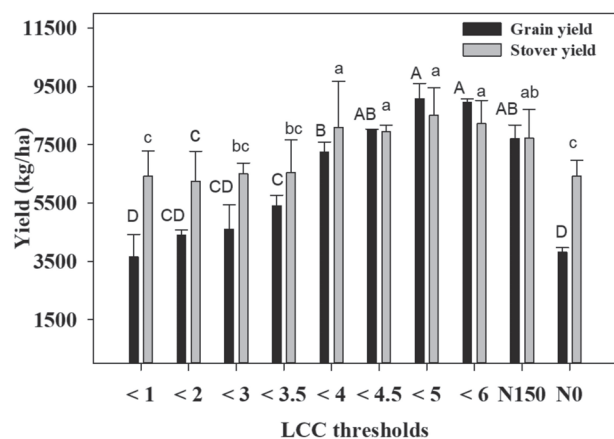


Fig. 2. Relationship between LCC-based N fertilizers application and grain yield of maize during 2016 and 2017

Regression analysis

Relationship between grain yield and LCC thresholds was strongly established in 2016 and 2017 (Fig. 3) ($r^2 = 0.77$). Grain yield estimated at LCC ≤ 5 thresholds was 7,023 kg/ha. It was comparable with recommended N dose at fixed intervals (7,381 kg/ha) (Fig. 3) registered $< 5\%$ difference. Across years and thresholds use of LCC with LCC ≤ 4.5 threshold for N management in hybrid maize resulted in application of 120–150 kg N/ha, thus saving up to 30 kg N/ha as compared to 150 kg N/ha in 3 equal splits at fixed growth stages. It has resulted in 18–36% saving of fertilizers with similar yield levels. The yearly variability was due to soil and climatic condition particularly rainfall. The LCC ≤ 4.5 threshold seems to be optimum for need-based N application to hybrid maize.

Plant nitrogen uptake and efficiency

Nitrogen uptake by grain and stover was significantly ($P = 0.05$) enhanced by LCC thresholds in spite of lower N rate as compared to the recommended N at fixed intervals. The increase in N uptake was however, significantly up to LCC ≤ 5 in both the years (Table 2). The increase in N uptake by three-fold with LCC ≤ 5 based on N application as compared to without N application. Further, 10.2% increased N uptake in LCC ≤ 5 threshold as compared to recommended N whereas total N uptake followed the similar trend as observed in grain yield. Thereby it was confirmed that grain yield of maize was delivered by the amount of N uptake by the crop. Earlier studies have also shown that the uptake of N increased significantly up to 150 kg N/ha applied as per LCC and SPAD meter (Kour *et al.*, 2007; Ghosh *et al.*, 2016). Agronomic efficiency of N (AE_N) and partial factor productivity (PFP_N) at high N rates are likely

Table 2. Economics, nitrogen uptake by plant parts, agronomic efficiency (AE_N) and partial factor productivity (PFP_N) of nitrogen in hybrid maize as influenced by N application based on leaf-colour chart thresholds under irrigated condition (pooled data of 2 years)

Treatment	Economics				N Uptake (kg/ha)			AE_N (kg grain/kg N applied)	PFP_N (kg/kg N applied)
	Cost of cultivation ($\times 10^3 \text{ ₹/ha}$)	Gross returns ($\times 10^3 \text{ ₹/ha}$)	Net returns ($\times 10^3 \text{ ₹/ha}$)	Benefit: cost ratio	Grain	Stover	Total		
LCC threshold ≤ 1	40.8	50.2	9.5	1.23	67.0	25.3	92.3	23	83.2
LCC threshold ≤ 2	40.8	59.1	18.4	1.45	80.6	31.3	111.9	38	98.5
LCC threshold ≤ 3	40.8	61.7	21.0	1.51	99.4	34.4	133.8	43	102.7
LCC threshold ≤ 3.5	40.8	71.4	30.7	1.75	115.2	48.7	163.8	58	117.6
LCC threshold ≤ 4	41.1	95.1	54.0	2.31	119.2	51.2	170.5	41	81.0
LCC threshold ≤ 5.5	41.8	104.0	62.2	2.49	135.9	66.7	202.6	30	54.9
LCC threshold ≤ 5	42.1	117.5	75.3	2.79	125.6	60.9	186.5	22	42.9
LCC threshold ≤ 6	42.5	115.6	73.1	2.72	119.3	55.8	175.1	18	35.4
150 kg N/ha	42.2	100.2	57.9	2.37	124.9	59.1	184.0	21	40.8
N_0	36.4	52.3	16.0	1.44	54.2	21.1	75.3	0.0	0.0
SEm \pm					3.7	1.8	7.4	1.6	2.6
CD (P=0.05)					11.0	5.4	21.9	4.8	7.8

due to greater N application coupled with similar yield potential (Table 3). Significantly maximum grain yields recorded at $LCC \leq 5$ has AE_N 30 kg grain/kg N applied it

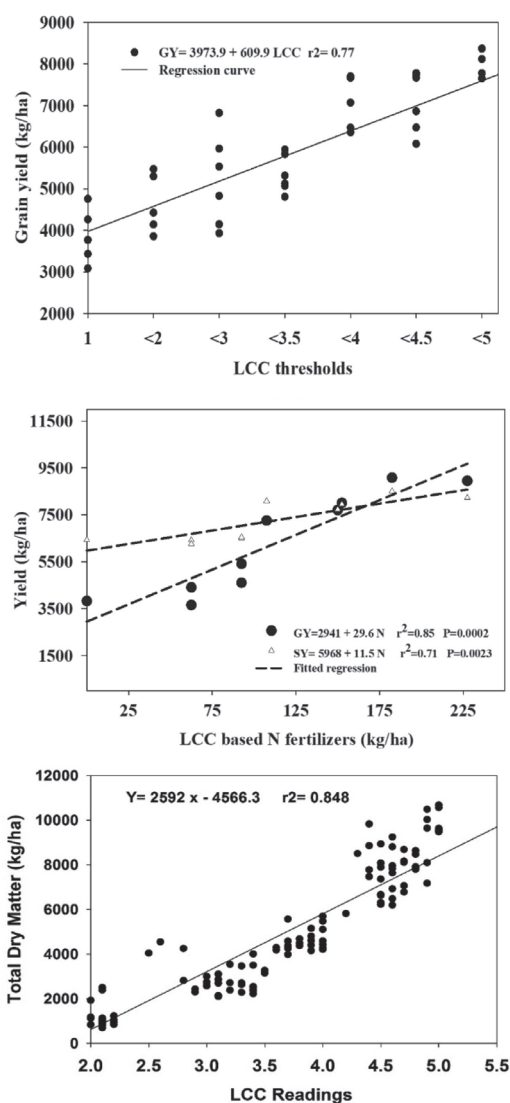


Fig. 3. Relationship between LCC-based and regional recommended nitrogen fertilizers application and grain yield, LCC thresholds on grain yield and total dry matter of hybrid maize. Data points are average of 2 years and 3 replications.

Table 3. Correlation between growth, yield components and quality of maize as influenced by precision nitrogen application based on leaf color chart thresholds under irrigated condition

Variables	Grain yield (kg/ha)	Dry matter at harvesting (g/plant)	Total N uptake (kg/ha)	AE_N (kg grain/kg N applied)	LCC readings at 60 DAS
Grain yield (kg/ha)	1.00				
Dry matter at harvesting (g/plant)	0.901**	1.00			
Total N uptake (kg/ha)	0.891**	0.904**	1.00		
AE_N (kg grain/kg N applied)	0.770*	0.548	0.636	1.00	
LCC readings at 60 DAS	0.834**	0.793*	0.658	0.720**	1.00

*P=0.1; **P=0.05

was further reduced when N applied based on $LCC \leq 6$ and RDN. Similarly, PEP_N at $LCC \leq 5$ recorded 54.9 kg/kg N applied. However, N application based on $LCC1$ to $LCC \leq 4$ has recorded higher AE_N and PEP_N due to lower N rate. Since grain yield response to applied N follows law of diminishing returns, number of workers (Kour *et al.*, 2007; Singh *et al.* 2007a; Singh *et al.* 2007b) have reported a decreasing trend in AE with increasing N rate due to higher values of AE at lower N rates.

The regression models developed from the data collected from field experiment were tested on an independent data set obtained from a field experiment conducted in 2016 and 2017. Root mean square error (RMSE) was used to calculate the fitness between predicted and observed data at final harvesting. Low values of RMSE indicate small deviation between predicted and observed grain yield under different LCC thresholds. The results showed that RMSE for yield prediction from 11.5%, 16.0%, 22.5% and 14% at $LCC < 4.0$, < 4.5 , 5.0 and 6.0, respectively, with overall across the threshold was 18.6% ($r^2=0.86$, $p<0.0001$). The agreement between the observed and predicted yields was fairly good for LCC thresholds. Lower RMSE values indicated that it can predict yield satisfactorily. Our results are in conformity with that of Singh *et al.* (2012) and Ali *et al.* (2014) in rice, who reported LCC-based N application has predicted potential yield advantage over fixed N rates.

Economic analysis

The economics of maize depends on relative yield of maize as influenced by LCC-based N management and prevailed market price of the produce (Table 4). The total cost of cultivation was varied from ₹40,745/ha to ₹42,490/ha during 2016 and 2017 respectively. Major varied cost was towards N fertilizer for different LCC thresholds. Average over 2 years, gross returns realized were higher by N application based on $LCC \leq 5.0$ (₹117,438/ha) and lowest without N application (₹52,295/ha). In hybrid maize, the fertilizer N application based on $LCC \leq 5$ was

more profitable than any other treatment combination. It was mainly owing to higher yield levels coupled with lower cost of cultivation in terms of fertilizers. It has resulted additional net profitability of 28.8% to 31.5% over the recommended N application at fixed intervals. Shantappa *et al.* (2011) also reported that, LCC5-based N application resulted in increased net returns, benefit: cost ratio over recommended N and farmers practice. Shukla *et al.* (2004) in rice and wheat also realized 20–23% more returns by using LCC over recommended N; however, it varied with varieties and hybrids as well as time of sowing.

Applied N fertilizers can be used efficiently through LCC by matching N supply with crop N demand without sacrificing grain yield of hybrid maize in *Vertisol*. Optimum LCC threshold of $LCC \leq 4.5$ to 5 with basal 30 kg N/ha was found effective to achieve higher yield, enhanced N efficiency and additional economic benefit. LCC is a user-friendly, low-priced and effective tool for judicious use of N fertilizers in hybrid maize over fixed interval location-specific recommended N.

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