Indian Journal of Agronomy **61** (1): 64–69 (March 2016)

Research Paper

Evaluation of leaf-colour chart for need-based nitrogen management in maize (*Zea mays*) grown under irrigated condition of Mollisols

VEER SINGH[1], AMIT BHATNAGAR[2] AND AJEET PRATAP SINGH[3]

Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145

Received : October 2015; Revised accepted : January 2016

ABSTRACT

A field study was conducted at Pantnagar, Uttarakhand, during the rainy (*kharif*) season of 2013 and 2014 using leaf-colour chart (LCC) as a tool to know nitrogen demand in maize (*Zea mays* L.) crop and to evaluate and establish LCC threshold value for saving fertilizer N and achieve higher grain. The LCC-treated plots showed higher increase in grain yield/kg N applied over fixed time interval of N treatments. Using of LCC score 3.0 with 90 kg N/ha showed grain-yield equivalent to 120 and 150 kg N/ha applied at fixed time interval and gave higher recovery efficiency to the tune of 12.1–18.1 unit and 4.1–5.1 kg higher grain yield/kg fertilizer N applied, whereas LCC 5.0 resulted in significant higher grain yield. Application of fertilizer N with 1.0 unit increase in LCC score significantly enhanced grain yield but no response of fertilizer N was seen when applied at reproductive stage. Soil-available N increased significantly with increasing the LCC values and was significantly superior at LCC < 5.0 followed by 150 kg N/ha applied at fixed time interval. Leaf-colour chart-based N management reduced anthesis silking interval by 0.2–1.4 days compared to fixed time interval. Strong correlation was obtained for LCC score with N content and grain yield at the reproductive stage. Leaf-colour chart values against grain yield indicated that LCC 4.6 at vegetative stage and LCC 4.9 at reproductive stage can guide crop demand-driven N application to enhance yield and saving N in maize under irrigated condition of Mollisols in *tarai* region.

Key words : Grain yield, Leaf-colour chart, Maize, Nitrogen management, N-use efficiency

Maize or corn is the third most important crop in India after rice and wheat grown over 8.67 million ha with 22.26 million tonnes production having an average productivity of 2566 kg/ha, contributing 8% in national food basket (DACNET, 2014) but its productivity is markedly influenced by crop management practices and the technologies adopted, particularly nitrogen-fertilization strategy.

Maize growers in the moderately to higher rainfall areas in north India face severe biotic and abiotic challenges and in spite of using sufficient fertilizers and improved hybrids, yields do not achieve expected level. Although these soils were rich in organic matter content 4–5 decades earlier but due to growing of continuous double or triple crops in a year for the past 2–3 decades, low organic matter and nitrogen content in soil have became a major abiotic challenges for crop growth (Yadav *et al.,* 2000). Nitrogen being the most yield-limiting factor in maize, its stress reduces growth and yield and considered as a most crucial nutrient. Poor nitrogen utilization in maize crop is due to inclusion of excessive nitrogenous fertilizers by farmers in the absence of nutrient recommendations as well as without assessing the crop-N demand and crop stage. Furthermore, problem associated with this nutrient is the high mobility in soil, causing loss by heavy rainfall. Many research reports indicated loss of fertilizer N in cereal production from 20 to 50%. Fertilizer N losses in surface runoff range between 1 and 13% of the total N applied. Application of urea to the surface without incorporation, the losses of fertilizer N as NH_3 can be as high as 60% (Rochette *et al*., 2013), and generally greater with increasing temperature. Therefore, N management poses a serious challenge in addition to loss of N in such area having high rainfall and temperature. Hence, higher yield of maize on sustainable basis are of paramount importance in this region.

Fine-tuning rate and time by split application in order to coincide nitrogen availability with crop needs is the best management practice that would result in better N-use efficiency and yield. Different nutrient-management

[1]**Corresponding author Email:** veer1969_singh@yahoo.co.in
[1,3]Assistant Professor, Department of Soil Science; [2]Assistant Professor, Department of Agronomy, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar, Uttarakhand 263 145

approaches such as leaf-colour chart (LCC), Nutrient Expert, a computer-based decision support tool (Kumar *et al.*, 2014), chlorophyll meter (SPAD meter) etc. are the better options to increase fertilizer efficiency and productivity of maize. Therefore, it is essential to adopt appropriate N management method that can overcome any environmental problems or low nitrogen-use efficiency that results from excessive N application. In the literature, the guidelines available to date recommends the application of prescribed amount of fertilizer throughout the crop season based on threshold value of LCC but the nutrient requirement and its uptake by crop is different in different critical growth stages. Differences among corn hybrids for N-use efficiency are largely due to variation in the utilization of accumulated N before anthesis, especially under low N supply (Moll *et al.*, 1982), low nitrogen supply during floral initiation affects grain number and maize yield markedly due to poor kernel formation and increased abortion.

Since farmers generally prefer to keep leaves of the crop dark green, it leads to over-application of N fertilizers resulting in low recovery efficiency. The LCC, a simple and non destructive, easy to use and farmer friendly tool which gives a rapid and reliable monitoring of leaf greenness by visual appearance of spectral properties of leaves as indicated by LCC can be a better guide to the farmers for judicious and right time application of N. The leaf-colour chart is being successfully used to assess the efficient N management under diverse situations of soil, climate, variety, management etc. especially in rice (Witt *et al.,* 2005), but the technology for its use in maize has not been well established so far. Keeping all in view, current study was undertaken to find out the relationship of leaf greenness as measured by LCC with leaf N concentration, nutrient-use efficiency and grain yield and to establish threshold LCC values for guiding crop demand-driven need based-fertilizer N applications in maize.

MATERIALS AND METHODS

The trials were conducted during June, 2013 and 2014 on fixed plot at the Norman E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India. The site is located at foothills of *Shivalik* range of Himalaya having an altitude of 243.84 m above mean sea-level and 29^o N, 79^o 30' E under sub-tropical climate. The minimum temperature goes up to 2.0^{o}C in winter to maximum 42.0^{o}C in summer, while annual rainfall ranges from 1,200 to 1,650 mm out of which more than 85% is received during wet season (June to September). Soils are Aquic Hapludoll developed on calcareous alluvial sediments, medium textured with a high micaceous component. Soils are poor in drainage, firm silty clay loam up to 0.76 m depth with mollic epipedon followed by silt loam up to 1.50 m depth and relatively high in fertility. Plant-available water-holding capacity up to 1.5 m depth was 0.23 m. The soil was neutral (*p*H 6.9), low in salt content 0.11 dS/m and available N 187.4 kg/ha, medium in organic carbon 0.72%, available P 21.3 kg/ha and available K 186.8 kg/ha.

In both seasons, after attaining the field capacity, field was deep ploughed with disc plough followed by 3 harrowings to a depth of 30 cm then leveled and divided into plots of 24 m^2 each. Treatments were laid out in randomized block design with 3 replications. Nitrogen through urea was applied at 3 rates, viz. 120, 150 kg/ha and need-based N management options, using leaf-colour chart when N reached below threshold values. Recommended dose of P_2O_5 (60 kg/ha as single superphosphate), K_2O (40 kg/ha as muriate of potash) in all treatments (Table 1) including the control (no fertilizer N was received, T_1) and one-third N in 120 (T_2) and 150 kg N/ha (T_3) at fixed time interval treatments and 30 kg N/ha in need based/LCC value based N management treatments were applied basal before the sowing of maize seed. Maize hybrid seed of 'DHM 117' was sown manually on 10 June in 2013 and 12 June in 2014.

In treatments T_2 and T_3, remaining N was given in 2 equal splits at 30 days after sowing and pre-tasseling stages; however, in need-based N-management treatments (T_4–T_9); the remaining N fertilizer was adopted using LCC threshold values under the following application regimes, viz. T_4 (LCC < 3.0, from V6 to before silking), T_5 (LCC < 3.0, from V6 to before silking and LCC < 3.5 at silking), T_6 (LCC < 4.0, from V6 to before silking), T_7 (LCC < 4.0, from V6 to before silking and LCC < 4.5 at silking), T_8 (LCC < 5.0, from V6 to before silking), and T_9 (LCC < 5.0 from V6 to before silking and LCC < 5.5 at silking). At V6 stage, the sixth leaf of the plant was fully emerged with visible collar at leaf base but the seventh leaf was not yet visible, while at silking, silk appeared at cobs (crop entered in reproductive stage). During the season when leaf greenness of 60% leaves was noted below the LCC threshold value, 30 kg N/ha was applied through top-dressing. Crop-management practices for controlling weeds, pests and diseases were adopted as per recommendations when required. Total 4 irrigations were given to each plot to ensure proper soil-moisture level.

Leaf-colour chart consisting high quality plastic with 6 green colour shades which increased colour intensity with increase in number ranging from No. 1 (yellowish green) to No.6 (dark green) manufactured by Pretech Plast Pvt. Ltd., Bengaluru, Karnataka was used. Measurement of the LCC values were made in 2 ways, viz. before the silking stage, the middle part of the fully expanded first leaf with fully exposed collar from the top was placed in front of the colour strip for comparison while after the silk; ear leaf was used as index leaf. If the colour of a particular leaf was between 2 colour shades, the mean of the 2 values was taken as a reading. For accuracy, readings of 10 new and randomly selected leaves of plants at each observation period from each plot were taken. Since the leaf-colour reading is affected by the sun's angle and sunlight irradiance, LCC measurements were made by shading the measured leaf with the body of the observer at the same time. The LCC was used to assess crop N need at 10 days interval starting from V6 to silking stage.

Leaves of 5 random plants from each plot at fixed time interval were collected from V6 to silking stage to determine N concentration, while leaf dry weight was measured at harvesting of crop. To measure the growth and yield parameters, *viz.* plant and ear height and cob length, 5 randomly fixed plants were used during observations. Plants leaves were oven-dried with forced ventilation at 70 ± 2 °C for 24 h and weighed for dry-matter determination. Plants of 3 middle rows excluding the end hills of each experimental plot were used to record data on plant population, stover and grain yields and then converted on hectare basis. Grain yield of each plot was recorded at 15% moisture content on a dry-weight basis and then yield on hectare basis was calculated. Days from planting to tasseling and silking and anthesis silking interval (ASI) were estimated by regular observation up to the initiation of tassel and emergence of silk in at least 50% of plants in each plot. For soil analysis, a composite sample was taken from 0–30 cm depth from experimental area before fertilizer application and then analysis was carried out for initial soil properties. Soil-available N and leaves-tissue nitrogen content were determined using the Kjeldahls, method and expressed as kg/ha and mg/kg of leaves tissue respectively. Nitrogen-use efficiency (NUE) for each treatment was determined using the agronomic efficiency (AE) and the partial factor productivity (PFP) or recovery indices were computed as per standard procedures.

Data on growth, yield and N concentration in leaves for different N managed plots were analyzed statistically according to analysis of variance (ANOVA) using SAS 9.3. Least significant difference (LSD) test was used to test differences between treatment means at 0.05 level of probability.

RESULTS AND DISCUSSION

Growth attributes

Need-based N application showed higher leaf weight than to applying N at fixed time intervals (Table 2). In general, a higher leaf dry weight with increase in LCC scores indicated the higher uptake of applied N at real time. Increase in amount of nitrogen at fixed time interval resulted significant increase in plant height. Similarly, N applied with increase in LCC threshold value exhibited significant increment in plant height; moreover additional N application at silking stage at each threshold value tended to increase in plant height. This indicated that crop seems to respond to higher N dose. Nitrogen applied based on LCC card showed significant higher plant height than N applied at fixed time; however, plant height was awfully little non-significantly differed in those treatments where N was managed based on LCC scores at each interval till attaining of reproductive stage (V16) owing to crop potential for N uptake. Results indicated that crop in term of plant height respond more when N was managed at LCC score < 5.0 and < 5.5 at silking stage (T_9).

Yield attributes

Days to 50% tassel and silk emergence significantly responded to different N-management strategies and were observed slightly higher in N application at fixed time interval compared to LCC score-based N application, except

Table 1. Nitrogen rate and time of application in different nitrogen management strategies in maize during 2013 and 2014

Treatment	N rate (kg/ha) at each split	Time of N application (days after sowing) 2013	2014
T_1, No N	-	-	-
T_2, 120 kg N,ha in 3 equal splits	40	32,62	30,63
T_3, 150 kg N/ha in 3 equal splits	50	30,61	30,62
T_4, LCC < 3.0 from V6 – before silking	30	23,43	21,42
T_5, LCC < 3.0 from V6 – before silking and LCC < 3.5 at silking	30	23,43,65	21,42,63
T_6, LCC < 4.0 from V6 – before silking	30	23,35,46	21,33,44
T_7, LCC < 4.0 from V6 – before silking and LCC < 4.5 at silking	30	23,35,46,63	21,33,44,60
T_8, LCC < 5.0 from V6 – before silking	30	23,35,45,55	21,32,43,54
T_9, LCC < 5.0 from V6 – before silking and LCC < 5.5 at silking	30	23,35,45,55,61	21,32,43,54,58

LCC, Leaf-colour chart; V6, 6th leaf stage for LCC < 3.0 from V6 to before silking (T_4). In general, 50% tassel and silk emergence differed significantly among N applied at respective LCC values of < 3 to < 5 and silking stage (LCC < 3.5, < 4.5 and < 5.5). Anthesis silking interval (ASI) showed similar trend to that of 50% tassel and silk emergence. Nitrogen stress negatively affected ASI and was reduced with increasing N doses (Table 2). Maize crop in the control plot tasseled later than those from plots received fixed time and LCC-based managed N. At no N level, N stress delayed days to 50% tasseling and silking by 2.5–8.8 days and 3.0–10.7 days, respectively, over N-applied options. Kamara *et al.* (2012) and Abe *et al*. (2013) also reported that severe N stress delays tassel and silk emergence in maize. This suggested that increase in frequency and real time N application force emergence of reproductive parts of crop earlier. Nitrogen applied based on LCC scores except LCC < 3.0 from V6 to before silking (T_4) and LCC < 3.0 from V6 to before silking and < 3.5 at silking (T_5) showed lesser ASI than to fixed time intervals which suggested that real time N management reduced days to ASI and provide more time for grain development. Application of 30 kg more N over 120 kg at fixed time interval (T_3) resulted in significantly higher weight of 100 grains but lower than N applied at LCC values of < 4.0 from V6 to before silking and LCC < 4.5 at silking (T_7), < 5.0 from V6-before silking (T_8) and < 5.0 from V6-before silking and at < 5.5 at silking (T_9). However, in treatments T_4, T_5 and T_6; 100-grain weight was at par with grains weight under fixed time N treatments (T_2, T_3). Cob length increased non-significantly when N applied with increase in LCC score. Results obtained indicated that application of additional 30 kg N at silking stage resulted significant benefit in stover yield over respective LCC scores. Soil-available N was found to be reduced in all treatments over initial level. Available N differed significantly due to varied LCC thresholds and applied N levels and increased significantly with increasing the LCC values. This clearly indicates, increased soil fertility with the increase in LCC values along with N levels (Sarnaik *et al.,* 2010).

Validation of threshold LCC values and establishment of critical limit for yield

The results pertaining to nutrient-use efficiency and grain yield based on different need-based N-management strategies are shown in Table 3. The results indicated that there was increase in grain yield when N was applied with increase in LCC score. Similar findings were also reported by Singh *et al*. (2011) and Mathukia *et al*. (2014). Using additional 30 kg N/ha at silking stage (T_5, T_7, T_9) over LCC < 3.0, < 4.0 and < 5.0 did not significantly increase grain yield, however, increase in LCC score 1 unit over < 3.0 and < 4.0 at vegetative stage and over < 3.5 and < 4.5 at silking stage there was significant response to N application. Partial factor productivity and agronomic efficiency were found to be decreased with N management using LCC scores, as the score was increased either from < 3.0 to < 4.0 and < 4.0 to < 5.0 or < 3.5 to < 4.5 and < 4.5 to < 5.5 or applying 30 kg N/ha at silking over LCC < 3.0, < 4.0 and < 5.0. Application of 90 kg N with LCC score < 3.0 at vegetative stage (T_4) saved 30–60 kg N/ha and showed 26.8 and 40.0% higher partial factor productivity

Table 2. Growth and yield attributes of maize in different nitrogen management strategies (pooled data of 2 years)

Treatment	Total N applied (kg/ha)	Leaf dry weight (g/plant) at harvesting	Plant height at harvest (cm)	Days to 50% tasseling	Days to 50% silking	ASI (days)	100- grain weight (g)	Cob length (cm)	Stover yield (t/ha)
T_1	0	21.4	138.3	67.7	72.2	4.5	18.2	11.1	5.54
T_2	120	32.1	145.7	65.2	69.2	4.0	19.5	13.1	8.21
T_3	150	35.7	155.5	65.3	68.8	3.6	22.3	14.0	8.26
T_4	90	39.9	159.1	66.0	69.8	3.8	21.4	14.1	8.15
T_5	90	41.7	163.2	62.2	65.8	3.7	21.6	14.4	8.54
T_6	120	43.1	166.9	61.0	64.5	3.5	21.8	14.5	8.62
T_7	150	44.3	171.1	60.3	63.5	3.2	23.6	14.7	9.02
T_8	150	46.9	174.3	59.8	62.8	3.0	24.0	14.9	9.18
T_9	180	47.7	177.3	58.9	61.5	2.6	24.5	15.2	9.52
SEm±		0.31	1.30	0.26	0.27	0.36	0.47	0.36	0.07
CD (P=0.05)		0.93	3.90	0.78	0.80	NS	1.42	1.08	0.20

T_1, Control (no fertilizer N was received; T_2, one-third N in 120; T_3, 150 kg N/ha; T_4, LCC < 3.0, from V6 to before silking; T_5, LCC < 3.0, from V6 to before silking and LCC < 3.5 at silking; T_6, LCC < 4.0, from V6 to before silking; T_7, LCC < 4.0, from V6 to before silking and LCC < 4.5 at silking; T_8, LCC < 5.0, from V6 to before silking; and T_9, LCC < 5.0 from V6 to before silking and LCC < 5.5 at silking; ASI, anthesis silking interval and 4.1 and 5.1 kg higher grain yield/kg fertilizer N compared with 120 and 150 kg N applied at fixed time intervals, respectively. However, it was obtained higher with the tune of 12.9–21.2% with 1.7–2.8 kg more grain yield per kg applied N compared with N managed with LCC score < 4.0 to < 5.0. The comparable grain yield with 30 and 60 kg less N (LCC < 3) to the blanket application of 120 and 150 kg N at fixed time intervals was attributed to real time fertilizer N application. The low partial productivity factor and agronomic efficiency in N applied at fixed time interval options might be attributed to the non-matching of applied N with crop N demand. This indicated that synchronizing split N application with crop demand enhanced the recovery efficiency of nitrogen (Sen *et al.*, 2011).

In the critical limits for leaf N content, grain yield and nutrient-use efficiency-agronomic efficiency under different N-management options indicated that the critical values for reproductive stage were more by 0.3 units than vegetative stage in all cases (Table 4). However, critical scores were found to be ranged from 4.5 to 4.6 and 4.8 to 4.9 for vegetative and reproductive stages respectively. The critical levels below which leaf N content, grain yield and agronomic efficiency loss occurred owing to shortage of N seems to be 4.6,4.6 and 4.5 for vegetative stage and 4.9, 4.9 and 4.8 for reproductive stage, respectively, which indicated that fertilizer N should be applied below these levels to achieve optimum level.

Relationship between LCC values and leaves N content and grain yield

The LCC score at vegetative stage accounted 20–83% and 49–94% and at reproductive stage 81–88% and 94–98% of the variation in N content of leaves and grain yield, respectively, (data not shown). Leaf chlorophyll chart score showed in general significant and positive correlation with leaves N content (Mathukia *et al.,* 2014) and grain yield (Mahajan *et al.,* 2014) at vegetative and reproductive stages (Table 5). Strong relationship was obtained with the advancement in crop stage but reproductive stage

Table 3. Total nitrogen application, grain yield, nitrogen use efficiency under different N management strategies in maize (pooled data of 2 years)

Treatment	Total N applied (kg/ha)	Available N (kg/ha) at harvest	PPF (kg grain/kg N)	AE (kg grain increase/kg N applied)	Grain yield (t/ha)
T_1	0	148.4	0	0	2.87
T_2	120	171.7	33.1	9.1	3.97
T_3	150	178.8	27.1	8.1	4.09
T_4	90	161.7	45.2	13.2	4.07
T_5	120	167.2	34.6	10.6	4.15
T_6	120	170.8	35.4	11.5	4.25
T_7	150	175.4	29.0	9.8	4.35
T_8	150	176.2	29.5	10.4	4.43
T_9	180	181.7	25.2	9.2	4.53
SEm±		0.69	0.29	0.28	0.03
CD (P=0.05)		2.08	0.86	0.84	0.09

$T_{1,}$ Control (no fertilizer N was received; T_2, one-third N in 120; $T_{3,}$ 150 kg N/ha; $T_{4,}$ LCC < 3.0, from V6 to before silking; T_5, LCC < 3.0, from V6 to before silking and LCC < 3.5 at silking; $T_{6,}$ LCC < 4.0, from V6 to before silking; T_7, LCC < 4.0, from V6 to before silking and LCC < 4.5 at silking; T_8, LCC < 5.0, from V6 to before silking; and T_9, LCC < 5.0 from V6 to before silking and LCC < 5.5 at silking; LCC, Leaf-colour chart; PPF, partial productivity factor; AE, agronomic efficiency

Table 4. Relationship of leaf-colour chart values with leaf N content, grain yield and NUE-AE at vegetative and reproductive stages and their corresponding critical values.

Particular	Growth stage	Relationship	R^2	Critical value
Leaf N content	Vegetative	y = 2.852x + 18.214	0.802	4.6
	Reproductive	y = 4.283x + 12.436	0.748	4.9
Grain yield	Vegetative	y = 3.596x + 28.086	0.956	4.6
	Reproductive	y = 2.445x + 32.095	0.928	4.9
AE (kg grain increase/kg N applied)	Vegetative	y = -1.377x + 20.106	0.090	4.5
	Reproductive	y = - 0.990x + 18.796	0.098	4.8

NUE-AE, Nitrogen-use efficiency agronomic efficiency

Table 5. Simple correlation among leaf colour chart (LCC) score, leaves N content (%) and grain yield (t/ha) of maize at different days after sowing (DAS) at vegetative and reproductive stage (pooled data of 2 years)

Parameter	Vegetative stage (days after sowing)				Reproductive stage
	23	33	43	53	
LCC verses grain yield	0.380^{ns}	0.964**	0.978**	0.980**	0.979**
Leaves N content verses grain yield	0.437^{ns}	0.925**	0.819*	0.852**	0.987**
LCC verses leaves N content	0.457^{ns}	0.870**	0.794*	0.899**	0.987**

*P=0.05; **P=0.01

(0.979** to 0.987**) showed close relation than vegetative stage and if used between 30 days after sowing and silking stage, LCC seems to accurately predict grain yield of maize. It indicated that during early stage of crop there was sufficient N supply from the native pool of soil as well as from basal supply of fertilizer N. Highly significant correlation at reproductive stage for LCC score with other parameters proved more N demand at this stage and LCC can be successfully used to as a tool to guide the need-based fertilizer N application to obtain optimum grain yield.

It may be concluded that using LCC of < 3.0 with 90 kg N resulted in equivalent yield and saved 30–60 kg N/ha to that of N applied at 120 and 150 kg at fixed time intervals with high partial factor productivity and agronomic efficiency but statistically most beneficial grain yields were obtained with using LCC < 5.0. Inclusion of additional 30 kg N at reproductive stage failed to achieve significant increase in grain yield. Hence the strategy for need-based N management confirmed the usefulness of LCC threshold value of 5.0 during vegetative growth stage for obtaining higher grain yield and saving of N. Thus farmers should replace the fixed time and amount of fertilizer N application with the use of LCC tool to meet the crop N demand and achieve the optimum grain yield.

REFERENCES

Abe, A., Adetimirin, V.O., Menkir A., Moose, S.P. and Olaniyan, B.A. 2013. Performance of tropical maize hybrids under conditions of low and optimum levels of nitrogen fertilizer application–grain yield, biomass production and nitrogen accumulation. *Maydica* **58**(14): 141–50.

DACNET. 2014. Directorate of Economics and Statistics, DAC, Ministry of Agriculture, Government of India, New Delhi.http://eands.dacnet.nic.in/StateData_12–13Year.htm.

Kamara, A.Y., Ewansiha, S.U., Menkir, A. and Tofa, A.I. 2012. Agronomic response of drought-tolerant and Striga-resistant maize cultivars to nitrogen fertilization in the Nigerian Guinea savannahs. *Maydica* **57**(1–4): 114–20.

Kumar, V., Singh, A.K., Jat, S.L., Parihar, C.M., Pooniya, V., Sharma, S. and Singh, B. 2014. Influence of site-specific nutrient management on growth and yield of maize (*Zea mays*) under conservation tillage. *Indian Journal of Agronomy* **59**(4): 657–60.

Mahajan, G.R., Pandey, R.N., Kumar, D., Datta, S.C., Sahoo, R.N. and Parsad, R. 2014. Development of critical values for the leaf color chart, SPAD and Fieldscout CM 1000 for fixed time adjustable nitrogen management in aromatic hybrid rice (*Oryza sativa* L.). *Communications in Soil Science and Plant Analysis*. **45**(14): 1,877–93.

Mathukia, R.K., Rathod, P. and Dadhania, N.M. 2014. Climate change adaptation: Real time nitrogen management in maize (*Zea mays* L.) using leaf colour chart. *Current World Environment* **9**(3): 1,028–33.

Moll, R.H., Kamprath, E.J. and Jackson, W.A. 1982. Analysis and interpretation of factors which contribute to efficiency to nitrogen utilization. *Agronomy Journal* **74**(3): 562–64.

Rochette, P., Angers, D.A., Chantigny, M.H., Gasser, M.O., Macdonald, J.D., Pelster, D.E. and Bertrand, N. 2013. NH_3 volatilization, soil NH_4^+ concentration and soil pH following subsurface banding of urea at increasing rates. *Canadian Journal of Soil Science* **93**(2): 261–68.

Sarnaik, P.H. 2010. Nitrogen management in hybrid maize (*Zea mays* L.) through leaf colour chart. M.Sc. (Agriculture) Thesis, University of Agricultural Sciences. Dharwad, Karnataka.

Sen, A., Srivastava, V.K., Singh, M.K., Singh, R.K. and Kumar, S. 2011. Leaf colour chart vis-a-vis nitrogen management in different rice genotypes. *American Journal of Plant Sciences* **2**(2): 223–36.

Singh, V., Singh, Y., Singh, B., Thind, H.S., Kumar, A. and Vashistha, M. 2011. Calibrating the leaf colour chart for need based fertilizer nitrogen management in different maize (*Zea mays* L.) genotypes. *Field Crops Research* **120**(2): 276–82.

Yadav, R.L., Dwivedi, B.S., Prasad, K., Tomar, O.K., Shurpali, N.J. and Pandey, P.S. 2000. Yield trends, and changes in soil organic-C and available NPK in a long-term rice–wheat system under integrated use of manures and fertilizers. *Field Crops Research* **68**(3): 219–46.

Witt, C., Pasuquin, J.M.C.A., Mutters, R. and Buresh, R.J. 2005. New leaf color chart for effective nitrogen management in rice. *Better Crops* **89**(1): 36–39.