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Decision support tools for nitrogen nutrition in cereals - A review

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Abstract: Plant nutrient management, among various production practices, plays a pivotal role in enhancing productivity and quality of farm produce. Nitrogen being a dominant nutrient particularly in cereals, the main staple for majority, occupies central role in crop nutrition to enhance productivity, but when used in excess pollutes precious ground water. Various state of the art techniques in nitrogen nutrient recommendation aim to reduce fertilizer dose or tailor the supply of nutrient for the target yield besides enhancing use efficiency of applied fertilizers to address cost effectiveness and environmental concerns. Decision support tools, therefore, focus on real time plant nutrient supply as per crop needs. Leaf colour chart (LCC) is a simple, cheap, and user friendly tool to manage N more precisely. Again, Chlorophyll meter (SPAD) thresholds and optical sensors like GreenSeeker enable nutrient recommendation based on chlorophyll content, an indirect measure of plant nitrogen content. The LCC threshold of 4 or 5 could be adopted to save 20-50 kg N/ha particularly in crops with greater N demand or in crops grown under environment prone to N loss. The research carried out so far using these techniques reveal that in addition to enhancement of productivity, agronomic, physiological and recovery efficiencies are also improved in field crops. Therefore, there is a need to sensitize scientists, extension personnel, farmers and other stakeholders on LCC, chlorophyll meters, optical sensors and various web based ready reckoners for effective nutrient management in cereals.

Key words: Decision support system, Leaf colour chart, Nutrient expert, Optical sensors

The growing energy crisis in tune with population pressure is forcing researchers to find possible alternatives to raise factor productivity of field crops through tools for efficient fertilizer use. Achieving a balance between crop nutrient requirement and soil nutrient reserves is essential for maintaining high yield without any depletion in the soil fertility. Appropriate technology for fertilizer recommendation should consider the quantum of nutrients required at each stage of crop growth, and the soil ability to furnish the essential nutrients critical for profitable crop production. The practice of single fixed basal application or fixed time nitrogen management (FTNM) involving large quantum of nutrients most often results in excess availability in the beginning of the season and deficiency at subsequent middle and/or later parts of the season due to leaching, volatilization, fixation into unavailable forms etc., which in turn reduces fertilizer use efficiency and economic efficiency associated with poor productivity and concomitant environmental pollution due to nitrates. Split application or top dressing, the first agronomic practice for better fertilizer use, is followed at many instances to overcome these problems, nevertheless, the practice falls short from satisfactory. Therefore, there is a need to relook in to our traditional method of fertilizer recommendation. The various decision support tools introduced into farm production of late aim at precise and need based fertilizer recommendation. In the past, various aspects of fertilizer recommendation techniques were deliberated thoroughly by number of reviewers (Alam, 2005; Alam, *et al.,* 2006; Biradar *et al.,* 2005, 2012, 2012a; Bijay-Singh *et al.,* 2012, Costa *et al.,* 2001, and Harmandeep *et al.,* 2010). Nevertheless, the comprehensive coverage of different decision support tools is still very meager, and hence this effort.

Effective management of fertilizers, particularly N remains a major challenge to researchers and producers. To answer the questions of when, where and how much fertilizer nutrient need to be applied, we require a monitoring technique to evaluate the nutrient dynamics, availability, potential of supplying capacity of different resources *viz.,* soil, biological sources, fertilizers vis-a-vis crop requirement. The technique needs to be quick, effective and inexpensive, and should allow on-the-spot decision making (Patil, 2009). Recently, tools such as leaf color chart (LCC), chlorophyll meter (SPAD) (Varinderpal-Singh, *et al.,* 2011) and optical sensor - GreenSeeker are available for site-specific and need-based N management in cereals. In this background, the present review attempts to highlight certain pertinent issues on the necessity to use proven decision support tools to enhance fertilizer use efficiency with emphasis on economics and environment.

Leaf colour chart (LCC)

Blanket recommendations of fertilizer over large areas are not efficient biologically and economically because indigenous soil nutrient supply varies widely among rice (Dobermann and White, 1999), maize, wheat other cereals in Asia. In the quest of search for efficient methods, the concept of using spectral reflectance ratio to quantify colour of intact and active crop leaves emerged 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. Farmers could use leaf colour as a visual and subjective indicator of the crop nitrogen status and to replenish the need for N fertilizer application particularly in paddy, maize, wheat, sorghum *etc.* For instance, yellowing around midrib in maize due to N deficiency was considered for

N nutrition sometime back by researchers and growers in the US.

International Rice Research Institute (IRRI), the Philippines, therefore, considering leaf as ultimate indicator of soil supply and plant uptake has come out with a simple, farmer friendly and inexpensive leaf colour chart (LCC), a hand held plastic strip, that can be used as a complementary decision making tool to determine the need for N application in field periodically. Leaf color chart has now been used successfully to guide fertilizer N application in rice, wheat and maize (Bijay-singh *et al.,* 2002; Yadvinder Singh *et al.,* 2007; Varinderpal-Singh *et al.,* 2010, 2011).

The chart contains seven shades of green from yellowish green (No. 1) to dark green (No. 7) and is calibrated with the SPAD meter. It is a comprehensive and decisive apparatus that takes in to account soil supply, crop uptake and plant health on real time basis. It helps achieve need based variable rate of N application to crops based on soil N supply and crop demand. It is a simple, ideal and an eco-friendly tool to optimize N use, irrespective of the source of N; native soil N, applied fertilizer source *etc.* The LCC being cost effective and advantageous over the tedious, time consuming and costly leaf sampling, or laboratory analysis and consequent delayed recommendations, needs large scale adoption.

Leaf greenness or leaf N content is closely related to photosynthesis rate and biomass production, and is a sensitive indicator of changes in crop N demand during the growing season. Critical or threshold value of the LCC is, therefore, defined as the intensity of green color that must be maintained in the uppermost fully opened leaf of the crop plant. At critical/ predetermined stage of crop a calibrated dose of fertilizer N needs to be replenished whenever leaf greenness is below the critical LCC threshold. Thus, maintaining the leaf greenness just above the LCC critical value ensures high yields with need-based N applications thereby leading to high fertilizer N use efficiency. Farmers will benefit hugely if they can adjust N application through LCC as an indicator of actual crop condition and nutrient requirement (Varinderpal-Singh *et al.,* 2011).

The leaf colour chart that was originally developed for rice was found handy in other cereals/grasses such as maize, wheat, sugarcane *etc.* (Bijay-Singh *et al.,* 2002; Yadvinder-Singh *et al.,* 2007; Varinderpal-Singh *et al.,* 2010, 2011,) because of parallel leaf venation unlike complicated reticulated venation existing in dicotyledonous crops. Witt *et al.* (2005) reported its suitability in maize as indicated by spectral reflectance measurements performed on rice and maize leaves. They calibrated LCC values with the chlorophyll meter to fix the critical colour shade for local maize cultivar groups and crop conditions. Hawkins *et al.* (2007) stressed the need to consider relationship between measured N stress and optimum N rate required while making N rate decisions. Nitrogen stress determined with chlorophyll meter would help to reduce variation and improve the calibration of N stress with the nitrogen rate difference (ND) from the economic optimum nitrogen rate (EONR).

Farmers can use the LCC to qualitatively assess foliar N status and adjust N top dressing. Both methods, LCC and chlorophyll meter, are influenced by factors such as variety, plant density, crop stress that causes leaf chlorosis, soil nutrient status and climate. Therefore, these thresholds have to be calibrated to specific soil, climatic, and crop conditions (Witt *et al.,* 2005). Under practical on-farm situations, LCC proved to be as good as the chlorophyll meter in terms of high yield and improved N use efficiency. Its simplicity and cost effectiveness makes it superior over the latter. Now, recommendations are available and the chlorophyll meter and leaf colour chart are used currently in Asia for N management in rice and wheat (Singh *et al.,* 2002).

Fertilizer application at higher rate and in more splits have shown normal yield in various cereal crops. However, Alam *et al.* (2005), Bijay-Singh *et al.* (2002) and Shukla *et al.* (2004) proved that the current recommendation of three split applications for rice at specified growth stages is not adequate to synchronize N supply with crop N demand. Efficiency of LCC guided fertilizer application also depends on stage at which fertilizers supplied (Varinderpal-Singh *et al.,* 2011). Many researchers identified a critical LCC value of 4 is ideal than LCC 5 for need-based N management in transplanted rice (Yadvinder-Singh *et al.,* 2007; Budhar, 2005). In Southern Karnataka, Kenchaiah *et al.* (2000) reported that N recommendation based on LCC threshold 4 produced significantly higher grain yield over blanket and farmers' practice, and was on par with SPAD threshold 35 for N management. Further, agronomic efficiency of nitrogen was higher due to higher grain yield with lesser N application with SPAD and LCC besides saving of 10-20 kg N/ha.

Biradar *et al.* (2005) while studying comparative advantage of LCC opined that recommended dose of nitrogen was inadequate in achieving higher yields of irrigated rice in the TBP area whereas, economics indicated a higher benefit-cost ratio for LCC-5 than with RDN**.** However, in rainfed rice in Tamil Nadu, application of N fertilizers in splits @ 20 kg/ha at LCC threshold 3 was more beneficial in enhancing the growth and yield (Jayanthi *et al.,* 2007). Yadvinder *et al.* (2007) suggests that LCC-based N management assures optimal rice yields consistent with efficient N use and enhanced farmers' profits due to saving in the use of N fertilizers. A basal application of N @ 20 kg/ha though increased the growth parameters, it was not reflected in yields. But when LCC based N was supplied up to panicle initiation stage it enhanced yield. These findings highlight need for location specific research to develop recommendation for rice cultivars.

Avijit *et al.* (2011) indicated that threshold LCC values are known as those that optimize grain yield and NUE simultaneously. It has been reported that higher agronomic efficiency of N with consistent high grain yield could be regarded as an indicator for efficient N management in rice. On the basis of higher grain yield along with corresponding higher agronomic and recovery efficiencies and other parameters LCC < 5 for NDR 359, Sarju 52 and d" 4 for HUBR 2-1 (rice cultivars) was judged to be the critical value for proper N management.

Alireza and Anthony (2011) reported considerable opportunity to increase yield and N use efficiency (NUE) levels through improved N management using LCC in rice. The LCC threshold 4 with 25 kg N/ha and critical LCC value of 4 with 35 kg N/ha were found to be suitable for guiding N application to achieve the highest grain yield in Amol region of Northern Iran. Combination of LCC and chlorophyll meter based N management strategies resulted in optimum rice grain yield and high N use efficiency with less fertilizer N application than the blanket recommendation (Bijay-Singh *et al.,* 2012).

Similar to rice, N management in maize through leaf colour chart was useful to avoid lower fertilizer application besides applying at appropriate time so as to increase the productivity and profitability. Shukla *et al.* (2004) and Alam *et al.* (2005) reported that N applied based on crop need as determined by LCC was more efficient. Top dressing with 30 kg N/ha per dressing and maintaining the leaf greenness up to LCC-5 threshold recorded significantly higher grain yield (7749 kg/ha) of maize as compared to LCC-4 , LCC-3 and N levels of 20 and 10 kg/ha per top dressing (Sarnaik, 2010).

Further, Biradar *et al.* (2012) observed that applying the right dose of N (240 and 150 kg/ha in maize and wheat), coupled with the right time of application (*i.e.* 3-split applications) using LCC-based real time N management was beneficial in increasing the yield and profitability of maize-wheat system among farmers of northern Karnataka, India. Roland *et al.* (2013) reported that the LCC threshold 5 recorded significantly higher grain (4.4 t/ha) and straw yield (7.0 t/ha) of maize as compared to LCC threshold at 4 and 3. Significantly higher growth and yield components were observed with LCC < 5. Shukla *et al.* (2004) and Alam et al. (2005) also confirmed that N applied based on crop need as determined by LCC was used more efficiently. Thus, studies conducted so far in India and elsewhere proved practicability and efficiency of LCC in cereals *viz.,* rice, maize and wheat.

Soil and plant analysis development (SPAD) meter

The SPAD meter is a hand held, simple, quick and non-destructive *in-situ* tool for measuring relative content of chlorophyll in leaf that is directly proportional to leaf N content. Hence, the SPAD chlorophyll meter is used to diagnose the N status in crops and determine the right time of N application (Peng *et al.,* 1996; Ladha *et al.,* 2000). The SPAD meter measures how much of the light of a certain wavelength is absorbed (chlorophyll molecules) by the leaf sample. The instrument measures transmission of red light at 650 nm, at which chlorophyll absorbs light, and transmission of infrared light at 940 nm, at which no absorption occurs, before the measurement, instrument is calibrated-transmission is measured with no leaf inside. Minolta SPAD-502 chlorophyll meter is used to assess the nitrogen status of crops. It measures the greenness of leaves. Greenness is determined by the chlorophyll and nitrogen content. However, it is too expensive to be owned by farmers in developing countries which restricts its wide spread use.

Positive correlation was observed among leaf SPAD, canopy NDVI and chlorophyll content and leaf N. Correlations for canopy NDVI with leaf N and chlorophyll content at jointing and milking stages are similar to that for leaf SPAD. While SPAD can be used to evaluate chlorophyll content, NDVI can be used to assess nitrogen content (Hu Hao, *et al.,* 2010). Costa *et al.* (2001) reported that in maize hybrids SPAD reading increased as plants aged until silking based on SPAD based N application. In general, SPAD meter readings increased as N fertilization level increased at each measurement date. Applied N rates were significantly correlated with the SPAD meter readings (Miklos *et al.,* 2003).

In a long-term field experiment, four corn hybrids with six nutrient levels were examined (Ghosh *et al.,* 2013). Both the fertilization and the genotype affected the SPAD values wherein fertilizer effect was higher whenever the rate of N was relatively low. Further, they reported SPAD 36 with 35 and 25 kg N/ha top-dressings for rice could save N fertilizer by 20 to 35 per cent as compared to fixed time nitrogen management without reducing grain yield. Agronomic N use efficiency could be increased at high yield level using SPAD meter based N management.

In Brazil, Argenta and Sangoi (2004) established that when nitrogen was side-dressed at the soil surface in four equal doses, SPAD readings above 45.4, 52.1, 55.3, and 58.0 represented the adequate values for the stages of 3 to 4, 6 to 7 and 10 to 11 leaves per plant and at silking, respectively for higher grain yield. Similarly, Jian-hua *et al.* (2008) developed relationship between SPAD meter readings based nutrient management and maize grain yield. They reported that SPAD threshold 50 up to pre-tasseling stage enhanced grain yield as compared to lower thresholds. However, beyond SPAD 50 values the grain yield plateaued.

Varinderpal and Yadvinder (2010) opined that the SPAD and LCC have emerged as diagnostic tools which can indirectly estimate N status of the growing crops and help to define time and quantity of in-season nitrogen fertilizer top dressings in rice and wheat. The point to be noted is supplemental application of N fertilizers should be synchronized with the N needs of crop.

Harmandeep *et al.* (2010) revealed that real-time N management based on leaf color for less than critical greenness resulted in application of 60 to 120 kg N/ha with rice yields being equivalent to those obtained with the blanket recommendation. While, in fixed-date variable rate N management strategy either 100 or 115 kg N/ha was applied, rice yields were equal to those produced by real-time N management or the blanket recommendation. Therefore, they opined that for easy adoption by farmers, the fixed-date variable rate strategy needs to be modified to allow the application of N across a wider seasonal range.

Optical sensors for N recommendation

Light absorption and reflectance are the characteristics of leaf which is typical in every crop and/or variety under a given set of growing conditions. Therefore, scientists use this characteristic as an indicator of plant nitrogen stress. Since chlorophyll absorbs red light, low reflectance and more absorption in this band indicates a healthy plant. Conversely, *t*he cellular structure of healthy plants reflects light in the near infrared band. When plants are under stress, red band reflectance increases and near infrared band reflectance decreases and *vice-versa* happens if plants are not stressed.

The Normalized Difference Vegetation Index (NDVI) is a unit measured by an optical sensor which is based on the reflectance at red and near infrared (NIR) regions. Optical sensor readings can be used for obtaining NDVI using a hand held GreenSeeker TM (NTech Industries Inc., Ukiah, CA, USA). NDVI measurements can range from -1 to 1, with higher values indicating better plant health. It has the ability to predict yield potential of crops, *viz.,* rice (Harrell *et al.,* 2011), maize (Baez-Gonzalez *et al.,* 2002; Teal *et al.,* 2006) *etc.*

Kailou *et al.* (2014) reported that the grain yield of rice increased significantly with increasing N rate, its relationship could be fitted by quadratic curve, and the equations of early and late rice indicated significant correlation ($r^2 = 0.88$ and 0.65, respectively). There were large changes among NDVI values from tillering to filling stage of early and late rice cultivars, but they reached 0.25 at heading and filling stage and did not change substantially thereafter. The regression equation between N rates and NDVI at heading stage was robust and was proved well by validation experiment. The grain yield of rice could be predicted more accurately by using NDVI at heading stage, and therefore, NDVI values ranging from 0.28-0.31 at heading stage can be considered enough to obtain more than 9 t/ha rice grain yields.

Syeda *et al.* (2014) observed that application of 220 kg/ha nitrogen to wheat produced maximum NDVI value (0.85) at grain filling stage. The correlation among NDVI at booting, grain filling, and maturity stages with grain yield was positive ($r^2 = 0.90$; $r^2 = 0.90$; $r^2 = 0.95$ respectively). Therefore, they concluded that booting, grain filling, and maturity could be good depictive stages during mid and later growth stages of wheat crop as found under agro climatic conditions of Faisalabad.

Yinkun *et al.* (2014) reported that NDVI became saturated when biomass reached about 4 t/ha and when plant N uptake reached about 100 kg/ha, whereas ratio vegetation index (RVI) did not reveal obvious saturation effect, however, it indicated that both indices performed similarly, and their relative errors (RE) were still large (> 40%). Although, the two indices only explained less than 40% of plant N concentration or N nutrition index (NNI) variability, the RE values were acceptable (< 26%). The results indicated some potentials of using the GreenSeeker sensor to estimate rice N status non-destructively.

Web based ready reckoners

Web based ready reckoners are nutrient management decision support systems developed to provide a fertilizer management strategy to attain the yield goal. Nutrient Expert (NE) is one such decision tool for nutrient management in hybrid maize, rice and wheat (Satyanarayana *et al.,* 2013). This helps farmers increase their crop yield and profit by suggesting a meaningful yield goal for specific site. The guidelines provided by this software are in consistent with the scientific principles of site specific nutrient management (SSNM). It provides field-specific nutrient recommendation to individual farmers for improved yields and farm profits (Kumar *et al.,* 2012). Walker *et al.* (2009) documented adoption of farm and regional level economic impact of a decision aid. Similarly, Patil (2009) also established variable-rate N application utilizing site specific management zones based upon a variable yield goal. Mirasol *et al.* (2012) used Nutrient Expert for hybrid maize in Indonesia and the Philippines. In Indonesia, it helped to increase grain yield (0.9 t/ha) and profit (US$ 270/ ha) over farmer's fertilizer practice (FFP). Similar improvement in yield and profit in wheat was reported by Kumar *et al.* (2012).

Satyanarayana *et al.* (2013) used Nutrient Expert based field-specific fertilizer recommendations for maize across farmers' fields in southern India. Results from 82 farmers' fields, demonstrated the utility of the decision support system tool in improving the yield and profitability of maize over FFP. Besides providing location-specific nutrient recommendations rapidly, the tool has options to tailor recommendations based on resource availability with the farmers. Jat *et al.* (2013) suggested 4R principles (Xinpeng *et al.,* 2014) of applying right source of nutrients, right rate, right time and right place is expected to increase nutrient use efficiency, productivity and farm profit from maize production.

Yield improvement with NE-based fertilizer recommendation could primarily be attributed to a balanced application of nutrients based on SSNM principles (IPNI, 2013). Limin *et al.* (2013) used Nutrient Expert for nutrient management in wheat. Field validation based on yield response and agronomic efficiency revealed an increased trend both in grain yield and gross profit, agronomic efficiency, recovery efficiency and partial factor productivity of nitrogen. Further, Sapkota *et al.* (2014) reported increased wheat production with NE-based recommendation supplemented with GreenSeeker guided nutrient management under no tillage system which could be carbon neutral. This combination of tillage and nutrient management strategy can be recommended for wheat production in north-west Indo-gangetic plain to increase yield, efficiency and profitability.

Efficiency of applied nutrients

Use of leaf colour chart and chlorophyll meter for N nutrition revealed that at maturity the aerial portion of corn had accumulated 3.9 g N, 1.65 g P_2O_5 and 11.1 g K_2O per plant (Lei *et al.,* 2000) and the ratio of NPK uptake was 1:0.42:2.85, indicating a higher K requirement of corn. Peak N uptake occurred between heading and silking stages. The amount of N uptake during this period was 46.4 per cent of the total N accumulated and averaged 0.3 g N/plant/day. The peak P uptake occurred between milking and full ripe stages which was 65.4 per cent of the total P accumulated and averaged 0.03 g P_2O_5/plant/day. The peak K uptake occurred between the milking and dough stages and was 68.6 per cent of the total K accumulated and averaged 0.4 g K_2O/plant/day.

The N and P uptake by grain and straw in maize increased significantly with the application of 150 kg N and 80 kg P (Manoj and Singh 2003). These levels recorded N uptake of 52.9 and 33.7 kg/ha in grain and straw, respectively. The higher phosphorus uptake by grain and straw was found to be 12.6 and 20.8 kg/ha, respectively. The K uptake in straw and grain were 9.89 and 80.94 kg/ha, respectively, and it increased with increasing levels of nitrogen and phosphorus.

Kenchaiah *et al.* (2000) attributed high agronomic efficiency of nitrogen (AE_N) in rice due to higher grain yield with lesser N application based on SPAD and LCC threshold with a saving of 20 kg/ha of N fertilizers. Similarly, Balasubramanian *et al.* (2000) observed higher AE_N and partial factor productivity of applied N (PFP_N) with SPAD based N management in rice. Further, Mahendra *et al.* (2001) also observed significantly higher AE_N exceeding 135 kg/ha due to SPAD based N application in rice.

Application of N based on LCC-3 and SPAD-32 received lower N of 60 and 70 kg/ha in dry and wet season, saved N up to 65 and 80 kg/ha, respectively than local recommendation (125-150 kg/ha) (Porpavai *et al.,* 2000). Kumar *et al.* (2001) and Balasubramanian *et al.* (2000) also reported increased AEN and PFP by SPAD-based application (75 and 80 kg N/ha in the rainy and winter season, respectively) in rice over recommended practice (135 kg N/ha).

Leaf colour chart based N management reduced the N fertilizer use by 29 kg/ha and importantly it also reduced the lodging, pest incidence and production cost of rice (Nguyen and Hu, 1999). Further, LCC or SPAD based N management reduced the fertilizer use by 18 per cent and increased the grain yield of rice by 29 per cent compared to farmers method (Hlatin *et al.,* 1999). Mohandas *et al.* (1999) also reported considerable saving (46-54 %) in N-fertilizer use, without sacrificing the grain yield due to SPAD based N management compared with locally recommended blanket N rates. Use of LCC 4 as critical value reduced the N fertilizer use by 20 kg/ha compared to five splits of urea application (Zaini and Erythrina, 1999).

In maize, Varinderpal-singh *et al.* (2011) observed that blanket recommendation of applying fixed N dose at fixed time intervals is not adequate for obtaining high agronomic and recovery efficiency of fertilizer N. Matching fertilizer N supply with crop demand using threshold LCC shade 5 saved 25–50 per cent fertilizer N. Similar results were also reported in rice and wheat by Ram *et al.* (2011). The fertilizer nitrogen top dressed with urea in maize using LCC saved 25-30 kg N/acre with 20-48 per cent higher FUE. Thus, it is assumed that, LCC or SPAD based N application in cereals could save 20-35 kg N besides improving the N use efficiency by 20-50 per cent.

On *Inceptisol,* Maiti *et al.* (2004) reported that SPAD and LCC based N application resulted in higher NUE over fixed-scheduling of N in rice. The results further suggested that SPAD 37 and LCC 5 were superior to SPAD 35 and LCC 4 for N. *AEN* was higher at lower LCC threshold values mainly due to lower fertilizer levels (Biradar *et al.*, 2005). Similarly, Alam *et al.* (2005) also reported on increase in NUE in rice in Bangladesh when the critical value for LCC was reduced from 4 to 3.5. While, Singh *et al.* (2006) obtained higher fertilizer N-use efficiency with need based N management using LCC-3 rather than LCC 4 as critical colour shade.

The nitrogen use efficiency can be increased with SPAD and LCC thresholds over blanket N (Maiti and Das, 2006). For wheat, LCC threshold 4 gave higher grain yield, N uptake and N use efficiency over 120 N kg/ha in 3 splits (Shukla *et al.,* 2006). In irrigated rice, nitrogen use efficiency could be significantly improved by reducing the amount of fertilizer N applied without sacrificing grain yield through need-based N management using LCC in the Indo-Gangetic plains of Northwestern India (Yadvinder *et al.,* 2007). In rainfed rice, application of recommended dose of nitrogen @ 20 kg/ha at LCC 3 value at bi-weekly observations after 21 days after rice emergence was found better method of nitrogen management (Jayanthi *et al.* 2007).

Thus, the blanket recommendations of applying fixed N dose at fixed time intervals should be replaced with need based fertilizer N management using LCC or SPAD meter in rice, wheat and maize for higher N use efficiency.

Economics

Blanket N was inadequate in achieving higher yields of irrigated rice in the TBP area (Biradar *et al.,* 2005). The higher benefit-cost ratio was obtained with LCC 5 than with RDN**.** The SPAD and LCC-based N application increased the grain yield, N-use efficiency and higher benefit: cost ratio (1.91). SPAD value of 37 with basal N at 20 kg/ha N was found adequate in the Indo-gangetic belt (Maiti and Das 2006). Shukla *et al.* (2006) made comparisons with the recommended N splits, in which a similar quantity of fertilizer N was applied, wherein LCC threshold 3 for Basmati-370 and LCC 4 for wheat gave 20 and 23 per cent higher net returns, respectively. In hybrid rice-wheat combination, the N application based on LCC 5 for rice and 4 for wheat recorded additional net returns of 28 and 31 per cent, respectively, over recommended N splits. Biradar *et al.* (2012) obtained improved AE_N (30.7) and return on investment (17.7) with N in three splits based on LCC mainly due to right time of N application in maize-wheat cropping system.

It could be concluded that blanket one time recommendation or fixed time split application of nitrogen nutrient is not adequate for obtaining higher productivity, and agronomic and recovery efficiencies of N in most of the cereals. Alternatively, the recent decision support tools *viz.,* LCC, SPAD, GreenSeeker, and Nutrient expert could be used effectively to recommend nitrogen for cereals. These are the best available decision support tools at present. Although these tools are superior to traditional system of split doses, these are not absolute methods as leaf colour or reflectivity is an overall indicator of plant health or leaf chlorophyll content in particular, nutrient status or plant processes in consonance with soil and environmental biotic and abiotic conditions, but never an indicator of nutrient nitrogen alone.

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