R-2312
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REVIEW ARTICLE   Agricultural Reviews, Volume Issue

Performance of Cereals under Need based Nitrogen Management Strategies: A Review

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10.18805/ag.R-2312

ABSTRACT

Cereals have large nitrogen requirement, but the demand for fertilizer is variable. Divergence between the supply and requirement of nitrogen can potentially hamper the crop growth as well as the environment, resulting in poor nitrogen use efficiency leads to economic losses. A balance between supply and utilization is required to optimize crop growth, economic returns and to maintain environmental sustainability which can be solved through need based nitrogen management which is nothing but application of inputs is according to the needs of the farm. Spatial variability is present in the fields but often they receive a same dose of fertilizers because they are treated by farmers as a homogenous unit. Through need based strategies, farmers will supply nitrogen fertilizers according to the demand of the crop which reduce the losses of N fertilizer. A precision agriculture approach to address the disparate spatial N requirements across a field is the use of a variable rate application guided by crop canopy reflectance sensors. Sensors like SPAD chlorophyll meter, greenseeker, rapid SCAN *etc* are used for determining the nitrogen need of the field crops. Many researchers across the globe are working on standardization of these sensors for different growth stages of the crop. Precision input management in cereals is lacking at present in most of the growing areas. A good amount of information on crop nutrition is available, but information regarding need based N management is lacking. This article reviews the work done on need based nitrogen management strategies in cereals.

Key words: Cereals, Greenseeker, Rapid SCAN, SPAD chlorophyll meter.

The modern production systems have negatively impacted the nutrient balance as well as soil fertility. Many studies have revealed that farmers are not applying fertilizers according to recommended doses which results in imbalance between nutrient supply and crop demand. Application of N more than requirement leads to ground water contamination mainly because of leaching of NO_3-N (Tremblay *et al*. 2012) and it results in low nitrogen use efficiency (NUE). In India, 48.7%, 43.4% and 7.4% of irrigated land under cultivation consists of small (less than 2 ha), medium (2–10 ha) and large (more than 10 ha) size farms and average fertilizer N use in the three categories was 148.9, 108.5 and 114.6 kg N ha^{-1}, respectively (All India Report on Input Survey, 2011-12). Singh *et al*. (2010) suggested that feeding the crop N according to the needs is the most appropriate fertilizer N management strategy to further improve NUE. Since plant growth reflects the total N supply from all sources, plant N status at any given time should be a better indicator of the N availability. Real time monitoring of plant nitrogen uptake and yield is needed for identifying fertilizer requirement and decreases the environmental risks associated with fertilizer N use (Ali *et al*. 2020). Inadequate prediction of yield and N uptake while using precision N management method might lead to either over or under fertilization of plants (Yao *et al*. 2012).

Assessment of crop N requirement is an important factor for the judicial application of fertilizers. Crop response to applied N varies from region to region and studies need to be done to find out how crop will respond to N application in particular location (Colaco and Bramley, 2018). The NUE of rice is very low across the world and the main reason behind this is lack of synchrony between N demand and supply (Dinesh *et al*. 2017). N management using through SSNM, SPAD meter and LCC gives higher grain yield and NUE as compared to blanket N recommendation (Yadav *et al*. 2017). From the last 15-20 years, active crop sensors are emerging as potential tools for the site-specific nitrogen management (SSNM) strategies (Ali *et al*. 2018). Active crop canopy sensors have been increasingly used to develop in-season SSNM strategies, allowing non-destructive real-time diagnosis of crop N status and N recommendations (Lu *et al*. 2020). Main advantage of these sensors is that they can

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How to cite this article: Karthik, R., Dhaker, D., Raising, L.P. (2021). Performance of Cereals under Need based Nitrogen Management Strategies: A Review. Agricultural Reviews. DOI: 10.18805/ag.R-2312.

Submitted: 22-06-2021 **Accepted:** 25-08-2021 **Online:** 06-10-2021

determine the leaf N content very quickly in a non destructive manner (Cao *et al*. 2017). These active sensors improve grain yield as well as the NUE and are ecologically viable. The new approaches to sensor based variable rate technologies *i.e.*, SPAD Meter (Soil Plant Analysis Development) or chlorophyll meter, Ramped calibration strips, rapidSCAN, Normalized difference vegetation index (NDVI), Greenseeker *etc*. can increase NUE without reduction in yield (Colaco and Bramley, 2018).

Equilibrium between demand and supply of N is needed for optimizing the plant growth as well as for preserving environmental sustainability. Crop sensors determine the nitrogen demand of the crop and guide the farmers in applying the fertilizer accordingly. Yao *et al*. (2012) reported that crop sensors are playing a vital role in in-season SSNM applications and it should have the characteristics like own light source, active and cheap. Crop N status can be determined non-destructively from the spectral reflectance of canopy due to good correlation between leaf chlorophyll and crop N status. Some reflectance based vegetation indices use a combination of wavebands such as the NDVI, normalized diûerence red edge (NDRE) and ratio vegetation index (RVI).

The chlorophyll meter and greenseeker have emerged as diagnostic tools which can indirectly estimate crop N status of the growing crops and help define time and quantity of in-season fertilizer N top dressings in cereals. Supplemental fertilizer N applications are thus synchronized with the N needs of crop. Naderi *et al*. (2012) proposed that SPAD values have a potential to find nitrogen deficiency in crops because leaf chlorophyll and crop nitrogen content are closely correlated, which helps the farmers to make nitrogen management better compared to current management practices.

Among the tested technologies for precision N management, a saving of N by 9.5 and 30 kg with greenseeker and SPAD, respectively, while enhancement of 18.4 kg N/ha by soil test crop response (STCR) was found compared with recommended dose of fertilizer on maize crop (Mohanty *et al.*, 2015). Saleem *et al.* (2010) proposed that spectral reflectance can be used to assess the nitrogen deûciency symptoms in wheat which helps the farmers to follow proper and quick fertilization. Heege *et al*. (2008) reported that the crop canopy sensors take measurements of reûected light at selected wavelengths and calculate vegetation indexes (*e.g.* NDVI, RVI) accordingly.

The NDVI is a widely employed scanner-based system used to estimate crop growth due to its close correlation with corn N status (Rambo *et al*. 2010) and grain yield (Inman *et al*. 2008). Tremblay *et al*. (2009) reported that the NDVI is a measure to assess N status of the leaf with the help of data collected from different satellites. The NDVI is a common measure to estimate crop N status from remotely sensed data from a variety of satellites (Tremblay *et al*. 2009), is strongly correlated with SPAD readings ($r^2 = 0.68$ to 0.90) (Han *et al*. 2002). Ali *et al*. (2018) noticed that proximal canopy reûectance sensors which are non-destructive can be used as tools for SSNM. Colaco and Bramley (2018) reported that N strategies based on sensor readings always results in higher nutrient use efficiency and environmental sustainability which is because of lower sensor N rates compared to traditional strategies. Titolo (2012) found that both NDVI and SPAD values are closely correlated with maize grain yield and helps us to predict the final yield. Edalat *et al*. (2019) proposed that there was a high correlation between corn grain yield and SPAD values ($r = 0.94$) and NDVI values ($r = 0.75$) at 35 days after planting. This demonstrates that SPAD and NDVI values at 35 DAP could be a good early indicator of final grain yield. Therefore, measuring SPAD and NDVI at 35 DAP is recommended for corn producers. Singh *et al*. (2017) reported that precision nutrient tools like Nutrient expert support system, greenseeker hand held sensors and leaf colour chart has shown promise to increase nutrient use efficiency of crops thereby reducing fertilizer related cost of production, increase farm profitability and minimizing environmental footprint.

SPAD meter

The SPAD 502 (Soil Plant Analysis Development) meter or chlorophyll meter is a portable diagnostic tool used for monitoring crop N status *in situ* in the field. It assesses the N content of the leaf by measuring relative greenness within few seconds. The SPAD readings are calculated based on two transmission values: the transmission of red light at 650 nm, which is absorbed by chlorophyll and the transmission of infrared light at 940 nm, at which no chlorophyll absorption occurs. The portion of light is absorbed by leaf and the leftover is transmitted and converts into electrical signal by a silicon photodiode detector. The amount of light in photodiode detector is inversely proportional to the amount of chlorophyll in the path of the light. Leaf chlorophyll content in SPAD meter is displayed in arbitrary units (0–99.9). The relationship between SPAD readings and leaf N content per leaf area is influenced by climatic factors and leaf characteristics, which shall be considered while using a chlorophyll meter to guide N management in fields (Xiong *et al.* 2015). Ata-ul-karim *et al*. (2016) found that there is a positive correlation between N concentration and SPAD values and nitrogen fertilizer doses in rice.

Ghosh *et al*. (2017) found that the SPAD based nitrogen management holds a great potential for improving fertilizer use efficiency without compromise in grain yield in cereals. It can make the future better for farmers as it reduces the cost of production and poses less harm to environment as compared to current fertilization practices. Gholizadeh *et al*. (2017) found that SPAD readings should be taken at panicle initiation of rice through which helps us to assess the leaf N content along with final yield. Xiong *et al*. (2015) found that there is a variable correlation between SPAD readings and leaf N status which depend upon factors like thickness and measurement position of leaf. Yuan *et al*. (2017) observed that SPAD values have to be taken from 2/3rd position from the leaf apex on the wider side of the leaf blade as it identifies the N content precisely. In South Asia, the centre portion of the fully expanded leaf from the top is being used for guiding fertilizer N applications based on SPAD measurements in rice, wheat and maize (Singh *et al*. 2020).

SPAD thresholds are affected by a number factors including the species, regional climates, soil type and N fertilizer management measures (Peng *et al*. 1996), resulting in significantly different thresholds. SPAD threshold value of 37.0-37.5 used for nitrogen management in varieties of Indo-Gangetic plains (Maiti *et al*. 2004) while 35 is used for nitrogen management in south Indian varieties (Nagarajan *et al*. 2004). Ghosh *et al*. (2013) proposed SPAD index of 36 as a threshold value for eastern India. Huang *et al*. (2008) reported that SPAD threshold value varies with thickness of leaves and generally it is two units more in thicker leaves. Duttarganvi *et al*. (2014) found that SPAD based N management with threshold value of 40 resulted in maximum yield in rice crop with 13% lesser N fertilizer use compared to farmers practice.

Akhter *et al*. (2016) reported that SPAD values can be used to guide N fertilizer applications for wheat for achieving higher NUE in light soils in irrigated spring wheat. Singh *et al*. (2013) observed that SPAD readings at maximum tillering revealed that application of 30 kg N ha^{-1} increased wheat yield by 1.0 or 0.5 t ha^{-1} when the reading was equivalent to or less than SPAD value of 32.5 or 42.5, respectively. Protein content of wheat also varies with nitrogen fertilizer levels. Takebe *et al*. (2006) found that there is a close relation between leaf chlorophyll content at the full heading stage and protein content in wheat grains at maturity and recommended the application of 30 kg N ha^{-1} if SPAD meter reading of the leaves at full heading stage was between 50 and 52. In case the SPAD reading at heading stage was between 45 and 50, application 60 kg N ha^{-1} was required to obtain a grain protein content of more than 120 g kg^{-1}.

In an acid lateritic soil and under mild winters in the eastern India, Ghosh *et al*. (2018) proposed that application of 25 kg N ha^{-1}, whenever leaf chlorophyll content was less than the SPAD threshold of 40 up to heading stage, resulted in higher wheat yield levels than those observed by following the local fertilizer N recommendations and agronomic and recovery eficiencies were increased by 58% and 15%, respectively. SPAD meter cannot be used to guide N topdressing at crown root initiation stage of wheat (about 3 weeks after sowing) because very little variation in leaf colour is observed due to application of a basal dose of N at sowing (Singh *et al*. 2018). The lower limit indicating severe nitrogen deficiency in the leaves was around 35 SPAD units whereas the upper limit of 45 SPAD units which represents an excess consumption. The critical SPAD values for wheat at critical growth stages needs to be examined by conducting experiment under diverse agro-ecological conditions with different wheat varieties.

Peng *et al*. (2012) proposed that large amount of N applied at tillering stage reduced the production of effective tillers and there were significant negative correlations ($P<0.05$) between effective tillers and dry matter accumulation at the jointing stage of wheat crop. They also found that higher dry matter yield at early growth stage recorded lower number of ear-bearing tillers and greater dry matter yield after blooming or heading produced higher wheat yield. Yao *et al*. (2012) noticed that chlorophyll meter based SSNM increased the partial factor productivity of farmers by 68% without significant change in grain yield. Ghosh *et al*. (2017) suggested that fixed time nitrogen management (FTNM) though fetched good economic return but incurred greater nitrogen fertilizer consumption than required to produce the expected yield. Moderate rate of N topdressing at medium SPAD was found best for precision N management in wheat crop aiming at greater profit with higher NUE. Their study suggests that SPAD meter based N management saved about 30% of the existing N fertilizer recommendation in fixed time nitrogen management. Maintaining SPAD threshold value of 42 with topdressing 20 kg N ha^{-1} at each time had significant positive effect on grain yield with a saving of N fertilizer as compared to FTNM. According to the research of Ghosh *et al*. (2017), the SPAD value of 42 was found to be critical for wheat in eastern India.

Ghosh *et al*. (2020) reported that a moderate rate (25 kg N ha^{-1}) of N topdressing with a moderate SPAD (36 for rice and 40 for wheat) conserved fertilizer N by 33.3% in rice and 18.8% in wheat compared to the farmer's practices without yield loss and increases agronomic efficiency (21.4%) and higher nitrogen recovery efficiency (60%). The main reasons for the improved NUE was the efficient use of soil N supply and better synchronization between soil N supply crop N demands. In maize crop, SPAD value gradually increases with age of the crop and decreases at maturity stage and SPAD value of different age and leaf are positively associated with grain yield (Kandel, 2020). Edalat *et al*. (2019) proposed that combination of leaf nitrogen, SPAD and NDVI in the regression equation can be used to assess grain yield of maize and found that SPAD meter worked better than the NDVI meter in identifying nitrogen deficiency in early growth stages of maize.

Greenseeker

Crop canopy sensors helps in estimating crop growth in a community rather than individual plant or leaf in an efficient way and mostly used for large scale applications than leaf sensors (Xue and Yang, 2008). Greenseeker is a device that measures the fraction of emitted light in the sensed area that is reflected back to the sensor (reflectance) and provides output as NDVI. The NDVI has been widely used for indirectly obtaining the information such as photosynthetic efficiency, productivity potential and potential yield (Thenkabail *et al*. 2000). Greenseeker optical sensor is an emerging tool for SSNM in cereals which use active radiation from red and near-infrared bands to calculate NDVI and generates sensor readings @ 10 readings per second. Sensor readings have to be collected at 50 cm top of the crop canopy in each and every plot leaving out the boarders. It gives the farmers precise information about scheduling of fertilizers. It uses active radiation from red and near infrared light emitting diodes to obtain reflectance data independent of solar illumination. The NDVI from greenseeker plays a vital role in identifying management zones (Sharp *et al*. 2004). The greenseeker can also be used for identification of management zones and nitrogen status in cereals like maize and wheat for improving nitrogen use efficiency (Erdle *et al*. 2011).

Greenseeker can be used only after crop develops a sufficient canopy because standing water in rice interferes with optical sensor measurements during early growth stages. The chlorophyll content in the cell is defined by the amount of light reflected in the visible region and amount of light reflected in the near infrared (NIR) region defines the living vegetation or biomass. Stone *et al*. (1996) studied the use of proximal sensors to identify N uptake and yield of winter wheat and found that NDVI measurements were highly correlated with N uptake and yield of winter wheat. Franzen *et al*. (2016) and Arnall *et al*. (2016) used the algorithm to apply fertilizer N to various crops based on NDVI measurements using greenseeker optical sensor and observed high fertilizer N use efficiency as compared when general recommendation was followed. Colaco and Bramley (2018) reported that sensor-based N management saves around 5-45% N compared to farmers practice without much reduction in the productivity in cereals.

Ali *et al*. (2015) investigated quantitative relationship between NDVI measurements with greenseeker and grain yield of rice at key growth stages and reported that R^2 values ranged from 0.49 to 0.63. Ali *et al*. (2018) reported that fertilizer N application should be based on the relationship between in-season greenseeker measurements and total N uptake at maturity. Yao *et al*. (2012) conducted an experiment on sensor based N application in rice and found that partial factor productivity of nitrogen can be improved by 48% by maintaining same yield when compared to farmer's practice with the help of greenseeker. Ma *et al*. (2014) reported that greenseeker based N management has improved the profit by $42 per ha with 43.3% reduction in N fertilizer use as compared to farmers' practice. Ali *et al*. (2015) suggested that NUE was improved by more than 12% along with high rice yield levels when N fertilizer management was guided by greenseeker as compared to when general N fertilizer recommendation was followed. Foster *et al*. (2017) found that sensor based nitrogen management in rice decreased the amount of total N applied, improving nitrogen use efficiency while producing similar yield to the existing practice and application of 60 to 90 lb N/acre preflood in combination with sensor-based approach optimized grain yield and NUE.

Singh *et al*. (2011) found that feekes 6 stage of wheat in north western India is the appropriate stage to decide the amount of site specific fertilizer N to be applied as top dressing. Hassan *et al*. (2019) reported that NDVI at booting stage may be used to assess grain yield of rainfed wheat, showing R^2 values ranging from 0.38 to 0.90 from stem elongation to late grain filling across the treatments. Feng and Yang (2011) correlated NDVI measured at jointing to filling stages with grain yield of wheat and found the values ranged from 0.31 to 0.82. Moreover, NDVI at heading stage can also be sensitive to yield changes at different N rates. Similar results were also found for wheat, showing a high positive correlation (R^2 = 0.78) between NDVI and grain yield at the booting stage (Kaur *et al*. 2015). Singh *et al*. (2017) reported that application of moderate amount of fertilizer N at planting and sufficient fertilizer N to meet the high N demand during the period between crown root initiation stage and maximum tillering stage before applying a greenseeker based fertilizer N dose at 2^{nd} irrigation stage leads to maximum yield along with greater fertilizer use efficiency in irrigated wheat. Greenseeker based N management has reduced the fertilizer use by 20-30 kg/ha without compromising the wheat yield along with improved agronomic as well as recovery nitrogen efficiency. Ratanoo *et al*. (2018) comprehended that applying comparatively lower doses at early stages and thereafter applying N doses using greenseeker is a powerful tool to decrease the total amount of N required without significantly sacrificing the grain yield in wheat crop.

Swamy *et al*. (2016) found greenseeker as a better tool for need based nitrogen management in *rabi* sweet corn because greenseeker based nitrogen management (NDVI threshold value @ 0.80) has resulted in highest cob yield, gross returns and net returns in sweet corn when compared to SPAD based N management as well as farmers practice. Li *et al*. (2016) reported that N application with the help of crop canopy sensor in maize crop reduced total N fertilizer use by 11% with no significant reduction in grain yield compared with uniform fertilization and variable-rate fertilization mitigated soil N_2O emissions, NH_3 volatilization and NO_3^- leaching by 10, 23 and 16%, respectively. Prakasha *et al*. (2020) reported that nitrogen management through greenseeker in maize has resulted in 24.56%, 79.00% and 51.34% increase in yield, agronomic efficiency and recovery efficiency respectively as compared to farmers' practice. He concluded that greenseeker can be effective tool in maize to achieve sustainable developmental goals of ending hunger and securing food security. Fabbri *et al*. (2020) reported that greenseeker based N management in barley reduced the N fertilizer use by 50% as compared to conventional nitrogen management while there was no significant difference in yield in both of them and the former one produced less greenhouse gas emissions compared to latter one.

RapidSCAN sensor

The RapidSCAN CS-45 sensor (Holland Scientific Inc., Lincoln, Nebraska, USA) is a recently developed active crop canopy sensor and it is a lightweight as well as convenient portable sensor with built-in global positioning system and red edge (RE) band along with red and near infrared bands.

Another advantage of the RapidSCAN sensor is that the sensor data collection is not influenced by measurement height in the range of 0.3 to 3m (Lu *et al*. 2017). It provides NDVI and normalized difference red edge (NDRE) as two default vegetation indices (VI) in addition to the R, RE and NIR wave band reffectance. Besides NDVI and NDRE, many different VIs can be calculated. Lu *et al*. (2017) found that this sensor can be used for predicting rice N status indicators at different growth stages. Zhang *et al*. (2019) reported that NDRE had a better rice yield prediction accuracy than NDVI from stem elongation to booting stage using the RapidSCAN sensor. It was also previously revealed that, at an early growth stage (before stem elongation), NDVI resulted in a better relationship with rice grain yield; however, on approaching maturity, NDRE performed better (Muñoz-Huerta *et al*. 2013).

Muñoz-Huerta *et al*. (2013) also found that NDVI reached saturation earlier than NDRE under various N rates which indicates that NDVI could be helpful in low-land rice at early growth stages, but is less useful at mid-growth to late growth stages. Using vegetation indexes with the red-light band, correlations with agronomic parameters were poor, while the red-edge band-based indexes (NDRE and RERVI) showed a linear relationship with agronomic parameters, allowing differences between N fertilizer levels to be distinguished. The two default indices (NDVI and NDRE) are good enough for rice N status diagnosis without the need of other indices. Although using the top VIs (R^2=0.65) significantly improved the prediction of plant nitrogen content compared with using NDVI and NDRE (R^2=0.52), as well as some improvements in the prediction of nitrogen nutrition index (R^2=0.51-0.59 vs. R^2=0.23-0.57), using NDVI and NDRE together could achieve the same N status diagnostic accuracy (63% and 76% at the panicle initiation and stem elongation and heading stages, respectively) as using the top vegetation indexes (Lu *et al*. 2017). This is an encouraging finding, which will make it easier for producers to use this sensor.

The combination of the two default indices (NDVI and NDRE) of the RapdiSCAN sensor was enough for precision nitrogen management strategy of rice which eliminate the need of incorporating other indices. The RapidSCAN sensor-based nitrogen management strategy with panicle and grain fertilizer recommendations resulted in similar yield as fixed nitrogen management by saving 24% N application rate and also improved the agronomic efficiency and partial factor productivity by an average of 33% and 32% respectively (Lu *et al*. 2020). Future studies are required for further evaluation of the RapidSCAN sensor-based precision nitrogen management strategy in diverse on-farm conditions and integrates it into high-yield rice management systems.

CONCLUSION

There is a close relationship between amount of applied N to soil and N content of grain, which ultimately determines the yield of crops. It is the challenge for researchers is to convert the applied N in soil to grain yield with maximum efficiency because N is one of the most critical inputs to cereals. In many regions farmers are used to apply nitrogen at levels that exceed the doses suggested by the government extension services. The reason behind apparently wasting money and degrading the environment by applying excess fertilizer than a crop can use is awareness that the general recommendations are not appropriate for their individual regions. It is very evident from the above literature that the researchers from India and aboard have emphasized the need for efficient fertility management especially nitrogen management under varying soil and agro-climatic conditions. Recently portable sensors have opened up a new approach to acquire crop growth information in rapidly and in a non-invasive manner.

Chlorophyll meter, green seeker and rapidSCAN sensor based nitrogen management study in cereals are gaining popularity from last decade across the globe and it can be further strengthened by finding the appropriate basal N rate and determining the precise timing for midseason N in different crops. It is clear that N use efficiency and environmental performance can be improved if better sensor-based algorithms can be developed that can more accurately provide N at efficient rates. By maintaining yields and mitigating environmentally costly N losses, sensor-based variable N application technology has the potential to be a powerful tool in sustainable precision agriculture. Most of the studies reported so far show that advantage of proximal sensing based N management lies in reduced N rates with almost no increase in yield. Based on the above studies, we can summarize that sensor based nitrogen management is yielding positive results and promises a better future for farmers. There is a need to study the detailed economic analysis of chlorophyll meter and senor based nitrogen management strategies. This will help the farmers in taking appropriate decision regarding nitrogen management in growing of cereal crops.

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