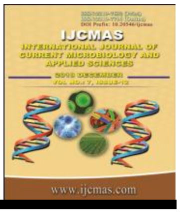
Int.J.Curr.Microbiol.App.Sci (2018) *7*(12): 1361-1384

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 7 Number 12 (2018)**
Journal homepage: http://www.ijcmas.com



Review Article https://doi.org/10.20546/ijcmas.2018.712.165

Sensor Based N Management Practices for Wheat in Indo Gangetic Plain- A Review

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ABSTRACT

Traditional farming has imbalance and excess use of chemicals and, in turn, to negative environmental impacts on soil health, groundwater, and atmosphere. Sensor based farming system should be more sustainable to reach economical and social profitability as well as the sustainable environment. A correct solution is to adopt precision farming, the best option for sustaining food production without declining the ecosystem. Precision technologies are used for integrating information about spatial and temporal differences within the field in order to match inputs to site-specific field conditions. The aims are to perform an investigation both on approaches and results of site-specific N management in wheat crop and to analyse performance and sustainability of agricultural practice. The earlier creation N management decisions, both the measurement and understanding of soil spatial variability and the wheat N status are needed. Complementary use of different sensors has improved soil quality relatively low cost. The red edge and near-infrared bands can penetrate into higher vegetation fraction of the canopy. These narrow bands better estimated grain yield, crop N and water status, with R^2 higher than 0.70. The various diagnostic tools and procedures have been developed in order to help wheat growing farmers for planning variable N rates. The field studies in which sensor-based N management system was compared with common farmer practices showed high increases in the N use efficiency of up to 368 per cent. These systems saved N fertilizers, vary from 10 per cent to about 80 per cent less N, and reduced residual N in the soil by 30-50 per cent, without deteriorating yields or grain quality; the sensor based N management on real-time sensing and fertilization had the highest profitability compared to fixed time and undifferentiated applications. Fixed time N management though fetched good economic return but incurred higher fertilizer N 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 N use efficiency. Their study suggests that SPAD meter based N management saved about 30 per cent of the existing N fertilizer recommendation in FTNM. Maintaining SPAD threshold value of 42 with topdressing 20 kg N ha^{-1} at each time had a significant positive effect on grain yield with a saving of N fertilizer as compared to FTNM.

Keywords

GPS, Nutrients, Precision agriculture, SPAD

Article Info

Accepted:
12 November 2018
Available Online:
10 December 2018

Introduction

The demand of food is increasing day by day to feed the ever growing population and the primary resources of agricultural production system (land, water, nutrients and atmosphere) are progressively degrading. The production system needs to be developed for enhancing food production, minimizing the use of agrochemicals and preserve or improving the natural resources (FAO 1995). Precision agriculture brings a revolution in agriculture and has been practiced commercially since (Crookston, 2006). It includes precise management of farm inputs at the right place and right time with right management practices. Precision agriculture offers to improve productivity and profitability of farm through improved management practices (Larson and Robert, 1991; Zhang *et al.,* 2002), leading to maintain sustainability (Mulla, 1993; Mulla *et al.*, 2002; Tian, 2002; Mulla, 2013). The technologies such as global positioning system (GPS), remote sensing, variable rate irrigation, fertilizer and sprayer controllers, robotics, and real-time decision making sensors are adopted. Globally, there is meager documentation about the adoption rates for precision agriculture in the developing country (Mondal and Basu, 2009). Keeping in mind about the future condition, precise technologies like sensor based inputs application are required to compensate the food demand. Sensors of the future could be based on satellites (Bausch and Khosla, 2010), airplanes (Haboudane *et al.*, 2002; Goel *et al.*, 2003; Haboudane *et al.*, 2004; Miao *et al.*, 2007), unmanned aerial vehicles (Herwitz *et al.*, 2004; Berni *et al.*, 2009), tractors (Adamchuk *et al.*, 2004; Long *et al.*, 2008), or attached to mobile robots (Astrand and Baerveldt, 2002) to record the parameters like weed density, crop height, leaf reflectance, moisture status and other properties, important for precise inputs management. These sensors have to able to relay information using wireless networks (Wang *et al.*, 2006; O'Shaughnessy and Evett, 2010) to compute and control in the field that are capable of varying the rates of irrigation, fertilizers, and herbicides at fine scale.

A huge amount of herbicide application in the field an intensive agricultural practice creates environmental and soil hazards. But the global need to increase food production is considered to be overriding. Therefore, production strategy for India in the 21st century must be through increasing productivity of the land with reduced production cost and higher inputs use efficiency (Babu and Reddy, 2000). The prime requisite is the promotion of health of the soil-plant-environment system without exploitation of over use and abuse of the inputs (Ayala and Rao, 2002). Wheat crop plays an important role on food security of the world. Precision inputs management in wheat is lacking at present in most of wheat growing areas. A good amount of information on crop nutrition is available, but information regarding need based N management in wheat is lacking.

Sensor based N recommendation

Agricultural crops have huge nitrogen requirement, but the demand for fertilizer is variable. Divergence between the supply and requirement of N can potentially hamper the crop growth as well as the environment, resulting in poor N use efficiency (NUE) leads to economic losses. High dose of N application often causes to a greater risk of ground water contamination as a result of leaching of NO_3-N which affects crop productivity and net return (Carpenter *et al.*, 1998; Ferguson *et al.,* 2002; Hashimoto *et al.*, 2007; Tremblay *et al.*, 2012). A balance between supply and utilization is required to optimize crop growth and economic returns and to maintain environmental sustainability.Now the challenge is to develop a simple sensor with two or three bands to estimate crop N concentration across different growth stages and environments for practical application. 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 (Wood *et al.*, 1992; Blackmer *et al.*, 1994). Several algorithms have been projected to relate the chlorophyll content and leaf N concentration from selected wavebands provided by optical remote sensing technologies (Walburg *et al.*, 1982; Filella *et al.*, 1995). Some reflectance sbased vegetation indices use a combination of wavebands such as the ratio vegetation index (RVI) and the normalized difference vegetation index (NDVI) (Rouse *et al.*, 1973). The NDVI is a common measure to estimate crop N status from remotely sensed data from a variety of satellites (Wright *et al.*, 2004; Tremblay *et al.*, 2009), is strongly correlated with SPAD readings (R^2 = 0.68 to 0.90) (Han *et al.*, 2002).

Blackmer *et al.*, (1995) used aerial images obtained at a certain wavelength that was particularly sensitive to canopy N levels to map N deficient areas within corn fields. They proposed the images of canopy reflectance could be used to detect portions of the field that were N deficient. Remote sensing is another areal precision applicator for obtaining information on crop N status for portions of or an entire field to characterize the spatial variability (Bhatti *et al.*, 1991; Atkinson *et al.*, 1992; Moran *et al.*, 1997). The chlorophyll in the leaves absorbs strongly in the blue (around 450 nm) and red (around 670 nm) light, and reflects in the green (around 550 nm) region of the light spectrum. Miao *et al.*, (2009) proposed that combination of chlorophyll meter readings and aerial or satellite remote sensing images seem to be a practical solution to in-season site-specific N applications in large fields. Perry *et al.*, (2012) conducted experiments using satellite imagery and multispectral cameras deployed on ground-based and airborne platforms. They found that the strong relationship between measured and estimated N across the 11 datasets with an R^2 of 0.60.Among the tested technologies for precision N management, a saving of N by 9.5 and 30 kg with green seeker and SPAD, respectively, while enhancement of 18.4 kg N ha^{-1} by soil test crop response (STCR) was found compared with recommended dose of fertilizer on the maize crop (Mohanty *et al.*, 2015).

The simplest, reliable and inexpensive tool for precision N management is the leaf colour chart (LCC), which can successfully be used to guide need-based nitrogenous fertilizers application in the crops based on spectral properties of leaves (Shukla *et al.*, 2004; Singh *et al.*, 2007, 2010). With a 'real-time' approach of N management, farmers take LCC readings at one week interval and apply fertilizer N wherever the LCC readings fall below the critical value. Fenga *et al.*, (2016) observed that the relationship between spectral indices and leaf N content varied under different experimental conditions (growth stages, cultivars, treatments, locations, and years). "Ramped Calibration Strip" (RCS), a precision another applicator for N fertilizer was developed and designed to predict crop N requirements based on the NDVI from wheat crop (Raun *et al.*, 2005; Arnall *et al.*, 2008;Raun *et al.*, 2008). This strip is a visual indicator, generous direct educational value to the producer because of the easily recognized signs of N stress or N adequacy.

The Greenseeker is another commercially available device which uses active radiation from red and near infrared light emitting diodes to obtain reflectance data independent of solar illumination. The NDVI from Greenseeker has been found useful in determining management zones (Sharp *et al.*, 2004). The Greenseeker can also be used in the determination of management zones and nitrogen status in the corn and wheat crop for improving NUE (Hong *et al.*, 2007; Guo *et al.*, 2008; Tremblay *et al.*, 2009; Li *et al.*, 2010; Shaver *et al.*, 2010; Erdle *et al.*, 2011). Cao *et al.*, (2017)suggested that the Crop Circle ACS-470 sensor can improve estimation of early season winter wheat plant N uptake and grain yield as compared to the Greenseeker sensor; but the precision nitrogen management strategies based on these two sensors perform equally well for improving NUE in winter wheat. Erdle *et al.*, (2011) reported that Crop Circle ACS 470 sensor was the most powerful and stable index for estimating winter wheat N status. Shiratsuchi *et al.*, (2011) noticed that the vegetation indices calculated with Crop Circle were the best indices for differentiating N rate effects on maize N status. Singh *et al.*, (2011) observed that sensor-guided fertilizer N applications resulted in high yield levels and high N-use efficiency of cereals.

Aerial and satellite imagery can be compromised by cloud coverage, for evaluating N status especially in the regions where this climatic feature is common in spring and summer months. Unlike aerial or satellite sensing, ground-based sensing need not be compromised by climatic factors and the sensors can be attached directly to an applicator so that the fertilization can be accomplished within seconds of crop sensing. Likewise, Greenseeker or Crop circle, Minolta Camera Company developed a portable chlorophyll meter or SPAD meter which can be used to estimate chlorophyll levels in leaves. Blackmer *et al.*, (1994) and Markwell *et al.*, (1995) suggested that the chlorophyll meter measures light transmission in the red (650 nm) and near-infrared (940 nm) parts of the spectrum to estimate leaf chlorophyll content. N is the key element in chlorophyll molecules and chlorophyll meter provides instant crop N status as SPAD value in a non-destructive manner. Using the Minolta SPAD 502 chlorophyll meter to monitor crop N status and applying N fertilizers; Blackmer *et al.*, (1993); Blackmer and Schepers (1994) and Blackmer and Schepers (1995) showed that crop-based approach would be an improvement over current soil-based approach to manage N. Chlorophyll meters have been used commonly to estimate crop N status non-destructively at crop growth stages to allow in-season adjustment of N fertilizer (Varvel *et al.*, 2007; Miao *et al.*, 2009; Singh *et al.*, 2010; Cao *et al.*, 2012; Ghosh *et al.*, 2013). Scharf *et al.*, (2006) found that chlorophyll meter readings were significantly correlated with the economically optimal N rate and yield response to N applied. They opined that chlorophyll meter reading was good predictor of corn yield response to N over a wide range of soil types and would be useful in making N-fertilizer management decisions. In a 10-year study in Nebraska, USA, Varvel *et al.*, (2007) found significant linear correlation between chlorophyll meter readings and corn yield, which was supported by Hawkins *et al.*, (2007). Miao *et al.*, (2009) also observed that chlorophyll meter has been commonly used to assess corn N status and refine in-season N management.

Singh *et al.*, (2012) suggested that overall treatment variations in SPAD readings were consistent with those in petiole nitrate-nitrogen (NO_3-N) concentrations. However, the ability of the SPAD meter to detect treatment differences varied with growth stage and growing season. Severe N deficiency can be detected about one month after emergence with SPAD readings, but as early as 2 weeks after emergence with petiole NO_3-N concentrations. Research in Nebraska littered the use of the SPAD meter for predicting in-season N deficiencies in the corn (Blackmer and Schepers, 1995). They used non-N-limiting reference strips was a benchmark that targeted improved mid-season N management in cereal production. This team in Nebraska further developed this approach, using the sufficiency index as a guide for applying mid-season N (Varvel *et al.*, 1997). Management of N in the winter and summer annual crops will likely to involve different approaches in order to understand sensor data with variable factors such as bare soil color, vegetative cover, chlorophyll content, leaf area index, biomass, plant height, etc. It is expected that sensors and improved algorithm technique create a better perceptive of soil-crop N dynamics in the future. Banerjee *et al.*, (2014) observed that the application of nutrient on the basis of the decision support system like Nutrient expert proved superior over farmer's practice as well as state recommendation where much higher dose of nutrients were applied. The Nutrient Expert based recommendation may be helpful in improving productivity and profitability of Maize cultivation in the laterite soil of eastern India.

Fixed time and precision N management in wheat

The information regarding the effect of fixed time and precision N management on growth and yield of wheat are presented here. Ghosh *et al.*, (2017) suggested that fixed time N management though fetched good economic return but incurred higher fertilizer N 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 N use efficiency. Their study suggests that SPAD meter based N management saved about 30% of the existing N fertilizer recommendation in FTNM. 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. The findings strongly suggest the revision of current recommendations in the rate and timing of N fertilizer application to maintain SPAD value 42 up to heading stage to improve growth and productivity of wheat in the subtropics of eastern India.

Crop growth and yield

In India the major issues for fixed time N management practices are: 1) declining yields, 2) declining factor productivity, and 3) declining soil health. There is a growing concern in sustainability cereal system as the growth rates of rice and wheat yields are declining. Proper management of nutrients in wheat cultivation can improve crop yield while reducing fertilizer N use (Dobermann and Fairhurst, 2000). Peng *et al.*, (2006) noticed that site specific nutrient management reduced N fertilizer use by 32 per cent and increased grain yield by 5per cent when compared with farmers' usual fertilizer practices. Banerjee *et al.*, (2014) found that the growth parameter as well as yield component and yield were significantly affected by different varieties and different levels of fertilizer using Nutrient Expert tool. Their study found that where fertilizer was applied on the basis of "Nutrient expert" recommendation gave highest yield and yield parameter values than that of farmers' practice. Sui *et al.*, (2013) observed that the dry matter production for wheat in farmers' practices was faster than that of the optimized N treatments at the vegetative and earlier reproductive growth stages; but at the later reproductive stage it became slower. Their study indicates that application of large amount of fertilizer at the time of sowing is not beneficial to maintain the physiological biomass at reproductive stage in farmers' practice. Positive correlations could be found between grain yield and spikelet. Grain yield of optimized N treatments was positively correlated with the spikelet per unit area, but the grain yield in FFP was not increased with the increase of spikelet per unit area (Sui *et al.,* 2013). Researchers suggested that the yield attributes, undersoil test crop response and site-specific N management performed better than farmers' practice (Mohanty *et al.,* 2015).

The chlorophyll meter was also effective in predicting N deficiency. Values of 40 and 45 SPAD units at booting stage of wheat are suggested as lower and upper limits for satisfactory N supply levels for the wheat cultivar (Vidal *et al.,* 1999). They suggested that the lower limit indicating severe nitrogen deficiency in the leaves was approximately 35 SPAD units; while the upper limit of 45 SPAD units, indicated an excess consumption for winter wheat. Site specific nutrient management generated a yield gain of at least 0.5 Mg ha^{-1} (12%) with 10% saving of fertilizer N when compared with FFP, clearly bringing out the positive effect of N management in site specific nutrient management (Singh *et al.,* 2002; Pathak *et al.,* 2003).

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. Singh *et al.,* (2002) observed that wheat responded to topdressing of 30 kg N ha^{-1} when the SPAD reading at maximum tillering was less than 44 and observed a 20% yield increase at SPAD value of 42 or less. Hussain *et al.,* (2003) determined a critical SPAD value of 42 for guiding need based N topdressing in wheat in Indo-Gangetic Plain (IGP) in Pakistan. However, Maiti and Das (2006) found that 37 is threshold SPAD value for guiding fertilizer N application to wheat in the eastern IGP where winters are mild and yields are relatively lower than those observed in western IGP.

Nitrogen use efficiency

Nitrogen is the key nutrient and the general recommendations are 100-120 kg N ha^{-1} for wheat (Prasad, 1990). One of the main reasons for the low recovery efficiency of N is that many farmers in the wheat belt apply 150 kg N ha^{-1} or even more (Cassman *et al.,* 1998; Prasad, 1999). Goswami *et al.,* (1988) showed that the recovery of 60 kg N ha^{-1} applied to rice was 35.4per cent by rice and 4.1per cent by the succeeding wheat (residual N); the corresponding value at 120 kg N ha^{-1} was 31.2per cent by rice and 4.6per cent by the succeeding wheat. The main causes for low recovery of N in wheat are inadequate and improper application of N fertilizer which causes volatilization, denitrification, leaching and runoff (Prasad and Power, 1995, 1997). Because processes other than ammonia volatilization are more operative in the rice growing season when monsoon rains are received or heavy and frequent irrigations are applied. Now the big issue is knocking that how to increase the efficiency. Mainly N use efficiency depends on the management practices which need to be optimized and adequate (Prasad, 2005). Banerjee *et al.,* (2014) it was found that the highest values for agronomic efficiency, physiological efficiency and recovery efficiency were also found where fertilizer was applied on the basis of the Nutrient Expert recommendation.

Application of N in the small amounts is a proven tool to increase N use efficiency. Most of N to wheat is applied in two or three split doses. In India for wheat the general recommendation for N application is in two split doses, half at sowing and rest at first irrigation (21-25 days after sowing), however, three split doses may be used on sandy soils (Bhardwaj, 1978). In China, 70% of the N dose is applied at sowing, 15% at the two leaf stage, and the final 15% at jointing (Shihua and Wenqiang, 2000). Researchers concluded that excess use or blanket application of N fertilizer during the initial stage may lead to poor N use efficiency. Overuse of synthetic N fertilizer has become wide spread in China (Ju *et al.*, 2009; Miao *et al.*, 2011), where the amount of synthetic N fertilizer used in wheat cultivation is 90% greater (190 kg ha^{-1}) than the average amount of the world (Heffer, 2009). Excessive N in the soil–plant system has contributed to soil acidification due to acidity generated during nitrification (Guo *et al.*, 2010). Excess N is also the main contributor to eutrophication of surface waters, nitrate contamination of groundwater and greenhouse gas emissions. Thus, fertilizing crops based on N requirement to enhance yield and at the same time reduce environmental pollution has become a major challenge for scientists, environmental groups and agricultural policymakers worldwide.Singh *et al.*, (2010) suggested that feeding crop N needs is the most appropriate fertilizer N management strategy to further improve N use efficiency. 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. The chlorophyll meter and leaf colour chart 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 rice and wheat. Supplemental fertilizer N applications are thus synchronized with the N needs of crop.

The NUE values for most of the cereal crops are estimated to be approximately 33% worldwide (Raun and Johnson, 1999). Agronomic N use efficiency decreased because of the increase in the rate of N supply (Peng *et al.*, 2002 and 2006). It was reported that the poor agronomic N use efficiency of farmers' practice was 6.4 kg kg^{-1} and 5-10 kg kg^{-1} in Zhejiang and Jiangsu provinces of China, respectively (Wang *et al.*, 2001; Peng *et al.*, 2006; Cao *et al.*, 2017) observed that the Crop Circle ACS-470 sensor could significantly improve estimation of early season plant N uptake (R^2=0.78) and grain yield (R^2=0.62) of winter wheat over Green Seeker sensor (R^2=0.60 and 0.33, respectively). The inefficient fertilizer management was due to ignoring the impact of spatial and temporal variability and difficulty in identifying the appropriate timing for fertilizer application. Low NUE values are due to loss of applied N from the soil–plant system via various pathways including gaseous plant emission, denitrification, leaching, surface runoff and volatilization. Enhancement of NUE by 10per cent in the production of cereal crops would result in savings of about US $5 billion per year and maintaining environmental sustainability (Gupta and Khosla, 2012). Soil moisture also has a significant effect on N availability, uptake and NUE. Furthermore, moisture has the potential to improve crops response to N, which would help in improving N fertilizer rate recommendations. Development of advanced sensor based tools for improving NUE, numerous methodologies are being proposed to estimate crop N requirements usingboth direct and indirect measurements of crop parameters. These methodologies often fail to account for the effect of temporal variability in environmental factors like soil moisture, which are closely tied with temporal variability in crop yield (Raun *et al.*, 2011). Ali *et al.*, (2015) suggested that N use efficiency was improved by more than 12% along with high rice yield levels when N fertilizer management was guided by Green seeker as compared to when general N fertilizer recommendation was followed.

Significant increases in Agronomic N use efficiency (AEN), nitrogen recovery efficiency (REN) and partial factor productivity of applied N (PFPN) were achieved through the site-specific N management practiced over farmers' fertilizer practices. The increase in AEN by 5.26 kg kg^{-1} (63%), REN by 0.10 kg kg^{-1} (59%), and PFPN by 7.72 kg kg^{-1} (26%) indicated greater saving of fertilizer N with the positive impact of site-specific N management on fertilizer N use efficiency (Khurana *et al.*, 2008). Singh *et al.*, (2012) found that LCC based N management strategy lead to AEN and REN as high as 29.2 kg kg^{-1} and 79.3%, respectively. Improved AEN and REN supported the results of Dobermann *et al.*, (2004) who noticed an exceeding of AEN and REN by 25 kg kg^{-1} and 60% respectively with high grain yield as efficient N management strategies for timely sown wheat. The farmers practice of applying blanket N doses at fixed growth stages does not take care of spatial and temporal variability in soil N supply and is not adequate for obtaining high agronomic and recovery efficiencies of fertilizer N in wheat (Singh *et al.*, 2012). Using an in-season N fertilization optimization algorithm, Tubana *et al.*, (2008) observed that fertilizer N use efficiency could be increased up to 41% in winter wheat and it was supported by Diacono *et al.*, (2013).

To optimize the tradeoff amongst yield, profit and sustainable environment, then management practices is to achieve better synchrony between applied and demand of fertilizer N, accounting for spatial variability in soil N supplies and crop N uptake. To accomplish this task, it will be necessary to utilize various precision agriculture tools like various soil and crop sensors that have the ability to sense crop N status and deliver spatially variable N applications based on crop N demand. Sensor like Greenseeker resulted 15% more NUE than that of farmers recommendation in wheat (Raunb *et al.*, 2002). Compared with traditional practice, NUE was significantly increased using active sensor based in-season N management strategies for winter wheat (Li *et al.*, 2009; Singh *et al.*, 2011) and rice (Yao *et al.*, 2012). A profit of \$25–50 ha^{-1} has been reported for active sensor-based variable rate N management of maize (Kitchen *et al.*, 2010). Similarly, Scharf *et al.*, (2011) noted that sensor-based N application increased partial profit and yield by \$42 ha^{-1} and 110 kg ha^{-1}, respectively, while N application rate was reduced by 16 kg N ha^{-1} compared to local farmers' practice. These results suggest that active sensor-based technology has a high potential for improving crop N management.

Therefore, farming system should be more precise to reach economical and social profitability as well as environmental preservation. The emphasis of precision agriculture is placed on practical application that shows a benefit to the farmer by providing tools that can help him manage an increasing size of enterprise when the economic margins are under great pressure. Therefore, without tools to recommend crop N need, leads to ignore the spatial differences in the field results in greater risk of N loss leading to considerable environmental degradation (Hong *et al.*, 2007). The main reasons for the improved N use efficiency was the efficient use of soil N supply and better synchronization between soil N supply crop N demands. Ghosh *et al.*, (2017) suggested that The SPAD based precision N management concept has been demonstrated promising agronomic potential with increased wheat yield and N use efficiency.

Soil fertility status

The importance of soil fertility cannot be ignored in sustainable agricultural production system. The soil fertility declines at a faster rate in the tropical and subtropical belts due to rapid decomposition of soil organic matter and subsequent loss of plant nutrients from the root zone as compared to that of the temperate zone. The maintenance of soil fertility under intensive wheat area is a challenging task in the coming years particularly in the tropical and subtropical belts. In this context, how fixed time and precision N management in wheat help in improving and maintaining soil fertility status is an important area to look at.

Real-time crop sensors have passive and active light technologies to ascertain N status through reflectance measurements in visible and near infrared wave bands. To accommodate spatial variability conditions and better match fertilizer N supply with crop N requirements, Franzen *et al.*, (2002) and Ferguson *et al.*, (2003) have developed a soil-based approach involving delineation of spatial variability into management zones as a means to direct variable N applications and improve NUE. Studies in India showed an increase in organic C due to the addition of organic residues (Brar *et al.*, 1998; Yadav and Kumar, 1998; Sharma and Prasad, 1999; Sharma *et al.*, 2000). Thus, cereal-cereal cropping system leads to a decline in soil organic carbon unless adequate fertilization and organic residues addition are practiced. The application of 144 kg N ha^{-1} to winter wheat at broad balk for 122 years caused only a 20% increase in available soil N. From a 3-year study at New Delhi, India, Prasad and Misra (2001) observed that an increase in soil organic C in a short span of time might not be noted; but the addition of fertilizer N and legume residues certainly increased available N in soils, which was more after wheat harvest than after rice harvest. Thus, addition of fertilizer N and legume residues definitely increases the labile N pool.

SPAD-based N management in wheat

Approximately 85% of wheat is grown in the IGP of South Asia. The major producers are India and China, accounting around 10 and 13 Mha, respectively. Other countries in the region have small areas of 2.2 Mha in Pakistan, 0.5 Mha in Bangladesh, and 0.6 Mha in Nepal (Singh and Paroda, 1994; Aslam, 1998). Adhikari *et al.,* (1999) reported that a current farm yield in Nepal, with modest fertilizer applications in wheat (50 kg N ha^{-1}) was2.7 t ha^{-1}. In Bangladesh, where more N is applied (70 kg N ha^{-1} crop^{-1}), the corresponding yield is 3.1 t ha^{-1}. India has also shown an average wheat yield of 4.8 t ha^{-1} with farmers' practices and5.4 t ha^{-1} under site-specific nutrient management (Ladha *et al.*, 2000).

Ghosh *et al.*, (2016) suggested that SPAD meter based N management saved about 30% of the existing N fertilizer recommendation in FTNM. 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. The SPAD value of 42 was found to be critical for wheat in eastern India. The findings strongly suggest the revision of current recommendations in the rate and timing of N fertilizer application to maintain SPAD value 42 up to heading stage to improve growth and productivity of wheat in the subtropics of eastern India.

The chlorophyll meter or SPAD meter has emerged as diagnostic tool which can indirectly estimate the crop N status and help in proper time and quantity of in-season fertilizer N topdressings. It instantly and nondestructively estimates the leaf N status as chlorophyll content. The fully expanded and youngest leaf is the most appropriate index leaf for SPAD in rice and wheat crop. The SPAD meter is able to provide a rapid and reasonably accurate estimate of leaf N content and the potential for applying principles and technology of precision farming to understand and control spatial and temporal variation in Malaysian paddy fields (Gholizadeh *et al.*, 2011). SPAD values can be used to guide N fertilizer applications for wheat in regions where winters are mild, soil is light and yields are relatively lower, this should be for achieving higher N fertilizer-use efficiency in light soils of irrigated spring wheat (Akhter *et al.,* 2016). The SPAD values of flag leaves were significantly affected by differential fertilizer management and having positive strong correlations with grain yield at different growth stages of wheat (Islam *et al.*, 2014). SPAD meter based N management saved 27 to 54% fertilizer N in rice in comparison to FTNM. Especially maintaining SPAD threshold 36, application of 35 and 25 kg N ha^{-1} could save the fertilizer N by 20 to 35% as compared to FTNM with a marginal positive impact on rice grain yield. The SPAD value of 36 was found to be critical for eastern India, unlike the value of 35 recommended for the Philippines in rice (Ghosh *et al.*, 2013). The split application of N fertilizer after heading increased dry matter accumulation after flowering, which led to increases in grain yield despite basal N application and topdressing at crown root initiation. Its findings strongly suggest the revision of current recommendation in the rate and timing of N fertilizer application, aiming to maintain SPAD value ≥40 up to heading stage and then improving growth and productivity of wheat in the subtropics of eastern India (Ghosh *et al.*, 2017).

The SPAD index has good correlation with leaf N concentrations as well as soil N status (Follett *et al.*, 1992). The SPAD-based management of N fertilization requires that SPAD readings are precise and reproducible. However, leaf physiological traits such as cell structure, chloroplast movements and water status can have important effects on leaf optical properties, therefore, increment on SPAD values by 2–3 units as relative leaf water content decreased from 94 to 87.5% in wheat leaves. The use of SPAD meter was very important to detect the nitrogen physiological rate for growth, yield and grain quality of wheat plant (ElHabbal *et al.,* 2009). The SPAD values were significantly affected by rice variety, growth stage, the leaf position and the measurement point on a leaf blade (Fang *et al.*, 2010). The ability of the chlorophyll meter to schedule fertigation is promising because it offers the possibility of conserving fertilizer and protecting the environment (Blackmer *et al.*, 1995). The relationship between SPAD readings and leaf N content per leaf area is profoundly affected by environmental factors and leaf features of crop species, which should be accounted for when using a chlorophyll meter to guide N management in agricultural system (Xiong *et al.,* 2015). The increasing of SPAD readings values with growth stage was observed at 55 DAT had a better relationship to leaves total N than 80 DAT on paddy crop Gholizadeh *et al.*, (2011). The higher correlation coefficient value indicated that the SPAD values of flag leaves up to anthesis are important for predicting grain yield in wheat (Islam *et al.*, 2014). Several workers (Murdock *et al.*, 1997; Yang *et al.*, 2003; Janaki and Thiyagrajan 2004) have reported significant correlation coefficient among the grain yield and leaf N content as well as with SPAD values recorded at crop growth stages. Xiong *et al.,* (2015) observed that a significant impact of light dependent chloroplast movement on SPAD readings was observed under low leaf N supplementation in both rice and soybean but not under high N supplementation. Furthermore, the allocation of leaf N to chlorophyll was strongly influenced by short term changes in growth light.

Crop growth and yield

In wheat, need based N topdressings are more complex than that of other cereal crop, because N application is linked with irrigation event. Generally, N is applied to wheat in two equal splits as basal and topdressing at crown root initiation stage (Meelu *et al.*, 1987). Suitable criteria are deficient to establish whether or not of wheat stage N application is required in wheat. The chlorophyll meter may be an effective tool in predicting N deficiency in wheat. SPAD meter readings for wheat at Zadok stage 37 were found good respond to a third application of N fertilizer in 91% of the cases (Zadoks *et al.,* 1974). However, Peltonen *et al.,* (1995) observed the SPAD meter measurement at Zadok stage 37-41 and Zadok stage 52-58 could help in identifying wheat cultivars responsive or non-responsive to N application. A critical SPAD value of 42 at mid-tillering in wheat corresponds with the result of Follett *et al.,* (1992) and Ghosh *et al.,* (2017) for wheat in Colorado and in eastern India, respectively.

Vidal *et al.,* (1999) found that the SPAD values 40 and 45 were found to be the lower and upper limits, respectively in Latin America for wheat. The lower limit indicating severe nitrogen deficiency in the leaves was approximately 35 SPAD units; while, the upper limit of 45 SPAD units, indicated 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. The SPAD readings were highly correlated with stem N% (R^2= 0.80) and leaf N% (R^2= 0.94) at heading, making SPAD an effective substitute of plant N content. Grain yield was also found to be highly correlated with SPAD readings at anthesis (R^2 = 0.88). However N accumulation in above ground biomass during early vegetative growth is less important than that of mid-tillering and early reproductive growth stages (Cassman *et al.,* 1996). This was supported by Ling (2000) and he concluded that wheat yield depends on dry matter accumulation after heading or blooming. Later, Singh *et al.,* (2005) concluded that SPAD meter can help in establishing the need for N application as required, which will largely depend on soil N status, date of planting and climate. Takebe *et al.,* (2006) found a close relation between SPAD value at heading stage and grain protein content at maturity. His study suggested that application of 30 kg N ha^{-1} (if SPAD value was 50-52) or 60 kg N ha^{-1} (if SPAD value was 45-50) at heading stage helped to obtain a grain protein content of more than 120 g kg^{-1} in Japan.

Using SPAD meter in South Asia, Singh *et al.,* (2002) noted that wheat responded to topdressing of 30 kg N ha^{-1} when the SPAD reading at maximum tillering is less than 44. They obtained a good increment of wheat yield by 20% when 30 kg N ha^{-1} was applied with SPAD value of 42 at maximum tillering. However, Hussain *et al.,* (2003) noticed a critical SPAD value of 42 for guiding N topdressing in wheat in Pakistan. In lower Gangetic plains of Bangladesh, application of 20 kg N ha^{-1} in split at 44 SPAD value was found to be ideal for wheat cultivation (Kyaw, 2003). Maiti and Das (2006) found that SPAD 37 as threshold value worked very well for guiding fertilizer N applications to wheat with a saving of 40.0-72.5 kg N ha^{-1} over the farmers' management practices without reduction in the grain yield in the eastern IGP. Application of 150 kg N ha^{-1} following threshold SPAD value of 38 produced wheat grain yield corresponding to that obtained with blanket application of 180 kg N ha^{-1} in two split doses in Pantnagar, India in the middle IGP (Singh *et al.,* 2010). Peng *et al.,* (2012) reported that large amount of N applied at tillering in wheat decreased the production of effective tillers and there was significant negative correlation ($P<0.05$) between effective tillers and dry matter accumulation at the jointing stage. They further noticed 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.

Now a day, big question arises regarding the basal N application, generally the farmers dig up a sensation of security against yield loss by applying a basal N dose. But the amount and timing of N application, has always remained a question when need based N management has been followed in rice and wheat. Witt and Dobermann (2002) noted that basal application of N can be skipped without reducing economic yield with higher N use efficiency. Shukla *et al.*, (2004) also supported that SPAD meter can be used for indigenous N supply and their study concluded that basal dose of 40 kg N ha^{-1} can provide an equivalent crop growth rate at crown root initiation stage with the basal application 60 kg N ha^{-1}.

Nitrogen use efficiency

Peng *et al.*, (1996) reported that SPAD based N practices received 56 kg N ha^{-1} and produced grain yield comparable to fixed-schedule N treatment of 90 kg N ha^{-1}. The SPAD based N treatment had larger REN, PFPN and an AEN of 45-110% greater than that of fixed time N management practices. They found that dry weight of dead tissue and unproductive tillers at flowering were greater in fixed time N management as compared to those of SPAD based N management. Excess tiller development and greater dead tissue biomass in fixed time N management practices were responsible for lower HI and NHI (nitrogen harvest Index) in comparison to SPAD based N management. Significant increase in AEN by 5 kg kg^{-1} (78%), REN by 0.11 kg kg^{-1} (61%) and PFPN 12 kg kg^{-1} (33%) due to SPAD guided N management over farmers' practice in China was noticed by Wang *et al.*, (2001). Their experiment suggested that during vegetative growth SPAD meter readings in farmers' practice treatments were larger than SPAD based N treatments, but the reverse was true during reproductive growth stages. Khurana *et al.*, (2008) suggested that SPAD meter can improve timing and/or splitting of fertilizer N and their result recorded increasing N recovery efficiency from 0.17 kg kg^{-1} in farmers' management practice to 0.27 kg kg^{-1} in SPAD based N management practices. However, the agronomic N use efficiency in previous treatment was 63% higher farmers' management practices. Abrol *et al.*, (2012) suggested that some modern tools such as precision farming technologies, simulation modeling, decision support system, and resource conserving technologies also help to improve NUE.

Cabangon *et al.*, (2011) found that IEN values of SPAD 35 were significantly higher than those in FFP where 180 kg N ha^{-1} was applied in four equal splits; whereas, SPAD 38 gave similar IEN with farmers' practice. Balasubramanian *et al.*, (2000) suggested that in many Asian wheat growing countries has generally shown that the same yield could be achieved through need based N management strategies with about 20–30% less N-fertilizer applied, over farmers' management practices. Though SPAD meter emerged as reliable tool to guide real-time need based fertilizer N recommendations in wheat, but appropriate strategies in wheat needs to be developed. Threshold SPAD values need to be worked out more rationally for different varietal groups of wheat. Suitable criteria for applying a basal dose of N need to be modified to discriminate soil types. Well planned studies to assess the effect of RTNM in wheat crop need to be carried out.

Economics of precision N management

Nitrogen is a crucial nutrient in cereal production, and can account for approximately 15-25% of production costs (Lambert and Lowenberg-DeBoer, 2000). To increase the N use efficiency with the positive objectives are to increase the profitability and environmental sustainability. There are two primary prediction methods for precision N application. The first method uses frequent soil tests from several areas in a field as well as GIS mapping (Koch *et al.,* 2004). The second uses optical reflectance measurements based on the crop's vegetation level to estimate N requirements (Alchanatis *et al.*, 2005; Raun *et al.,* 2005). There is no overwhelming evidence that the soil sampling and sensing methods increase profits enough in wheat production to recover the upfront capital cost for the technologies (Anselin *et al.,* 2004; Berntsen *et al.*, 2006). However, plant sensing is a more economically viable system than soil sampling and was found to be profitable (Ortiz-Monasterio and Raun, 2007). Biermacher *et al.*, (2006) conducted an economic analysis of 65 site-years of data from winter wheat N fertility studies in the southern plains of the United State to estimate the expected returns from uniform N versus a variable-rate applicator. They showed variable-rate N applications would result in significant N savings compared to uniform N application, when using N priced at $0.55 per kg. Cui *et al.*, (2008) noticed that in-season N management strategy based on soil test value significantly increased economic wheat yield by $144 per hectare, reduced residual nitrate-N content in the top 90cm soil layer and N losses by 81 and 118 kg N ha^{-1}, respectively. A profit of $25-50 per hectare has been reported for active sensor-based variable rate N management of maize crop (Kitchen *et al.*, 2010). Similarly, Scharf *et al.*, (2011) noticed that sensor-based N application increased profit and yield by $42 per hectare and 110 kg ha^{-1}, respectively, while the N application rate was reduced by 16 kg N ha^{-1} compared to local farmers' practice. These results suggest that active sensor-based technology has a high potential for improving crop N management. Compared with traditional practice, the NUE increased significantly using active sensor-based in-season N management strategies for winter wheat (Singh *et al.*, 2011).

In conclusion, the present study 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, in wheat crop under varying soil and agro-climatic conditions. As far as India is concerned, investigations on nitrogen management in wheat have been carried out meagerly in western India (Punjab and Haryana), and this kind of study is almost scanty in eastern India. The sensor based study under different wheat cultivar is also lacking in Indo Gangetic Plains of India. 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 wheat crop. Thereasonbehind 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. In many regions' farmers are used to apply nitrogen at levels that exceed the doses suggested by the government extension services. Realizing the problems of the farmers, the present study focuses on the use of crop canopy sensor (SPAD meter) for determining the dose and most critical stage for nitrogen application in wheat using seven cultivars as a need based N management approach for improvement in yield and nitrogen use efficiency. This study emphasizes the development of sensor based precise N management for improving partial factor productivity in wheat using SPAD meter in Indian sub-tropic. This will help the wheat growers in taking appropriate decision regarding nitrogen management in growing of wheat crop.

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How to cite this article:

Ved Prakash, Dayanidhi Chaubey and Suneel Kumar. 2018. Sensor Based N Management Practices for Wheat in Indo Gangetic Plain- A Review. *Int.J.Curr.Microbiol.App.Sci.* 7(12): 1361-1384. doi: https://doi.org/10.20546/ijcmas.2018.712.165