International Journal of Bioresource Science
Citation: IJBS: **10**(01): 09-18, June 2023
DOI: 10.30954/2347-9655.01.2023.2

ASSOCIATION FOR AGRICULTURE ENVIRONMENT AND BIOTECHNOLOGY

Research Paper

Hand-Held Optical Sensors for Optimizing Nitrogen Application and Improving Nutrient Use Efficiency

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Received: 23-02-2023 **Revised:** 28-05-2023 **Accepted:** 06-06-2023

ABSTRACT

The traditional use of fertilizers as per the recommendations has some limitations as it does not consider the site-specific and timely application. In this practice, less emphasis was given to resource use efficiency which may leads to various problems related to non-judicious use of essential inputs and agricultural sustainability. In terms of fertilizer nitrogen application, there are various approaches available in resent day agriculture. Among them, site-specific nutrient management through variable rate application can be considered as an advanced method for optimization of nitrogen requirement in cereal crops. By using optical sensors like chlorophyll content meter and crop reflectance sensors, nitrogen can be optimized by application at right time in a right amount. These optical sensors work on the greenness of the leaf which is a directly related component of leaf nitrogen content. The threshold value given by these sensors called as chlorophyll Index value or Normalized Difference Vegetative Index (NDVI) can be considered to estimate the nitrogen deficiency or nitrogen sufficiency in plant tissue. The application of these sensors has a greater impact on resource conservation and precise application of nutrients. However, in developing countries like India, the economic viability and limitation of application of these sensors in small land holdings for fertilizer nitrogen management are still not adequately studied. The review article focuses on benefits of use of various hand-held optical sensors for optimizing N application and N use efficiency.

HIGHLIGHTS

- Hand-held optical sensors are important tools for precision nitrogen management in crops.
- Optical sensors-based nitrogen management improves nutrient use efficiency and agricultural sustainability.

Keywords: Cereals, Green seeker, SPAD, Crop Circle, NDVI, Chlorophyll content meter

In the present context of the intensification of agriculture, most of the farmers focus on high input farming practices to obtain the potential yield of crops. In developing countries like India, most of the farmers are of small land holders; however, they tend to apply nitrogenous fertilizer non-judiciously. Nitrogen (N), one of the important primary nutrients, has been considered as a major input in the modern agricultural practices (Kumar *et al.* 2022). Cereal crops are highly dependent on external fertilizer inputs with more concern to nitrogen application (Singh, 2018; Nduwimana *et al.* 2020; Shankar *et al.* 2020). Nitrogen has a significant role in crop growth, performance and productivity (Yadav *et al.* 2017). The new generation

How to cite this article: Sairam, M., Maitra, S., Vishnupriya, K.K., Sahoo, U., Sagar, L. and Krishna, T.G. (2023). Hand-Held Optical Sensors for Optimizing Nitrogen Application and Improving Nutrient Use Efficiency. *Int. J. Bioresource Sci.*, **10**(01): 09-18.

Source of Support: IUCEA; **Conflict of Interest:** None

high yielding varieties and hybrids of cereals are highly responsive to nitrogen application and the yields are affected by the amount and time of application (Wan *et al.* 2022). Based on the above fact, the crop growers aim to increase the yields by the application of more nitrogenous fertilizers in an unscientific manner that results in low nitrogen use efficiency (NUE) (Bage, 2008). Further, the most of the Indian farmers do not consider the NUE, soil health and ecological concern while applying excess quantity of N fertilizer (Sairam *et al.* 2023). The application of N fertilizer varies in developing countries as per the land holding size of the farmers (Ren *et al*. 2019). In India, the usage of N fertilizer by small (up to 2 ha), medium (2 to 10 ha) and large (above 10 ha) landholders is 148, 108.5 and 114.6 kg N/ha respectively (Agricultural census, 2016). In developing countries of the world, N fertilizer is managed by blanket application or standard recommended doses given by agriculturists by calibrating the crop response data with similar climate and lands collected for larger area (Ju *et al.* 2016). Such standard recommendations cannot consider the dynamic spatial variability of the soil resulting in under fertilization or over fertilization.

On the other hand, N fertilizer nitrogen management in cereals can be well optimized by observing the crop demand and supply during critical stages of the crop based on site-specific management (Ram *et al.* 2020; Siqueira *et al.* 2022). Site specific nitrogen management (SSNM) is an alternative approach for blanket recommendation of nitrogen, which can efficiently optimize N requirement by calculating the inherent soil fertility status and crop nitrogen requirement together (Bana *et al.* 2020). SSNM can recommend the variable rate application by considering the spatial variability of the field and manage N need of the crop throughout the growth stages.

To estimate the real time N requirement of the crop, it is essential to quantify the N concentration of the leaves by appropriate tools (Putra, 2020). The leaf N content is directly related to the chlorophyll content which is further responsible for the greenness of the plant (Zhang *et al*. 2022). In general, farmers consider the leaf greenness as a subjective indicator for N topdressing during mid-stage of the crop. These visual predictions may be influenced by various factors such as sunlight and may result in inaccurate decision. In this regard it can be informed that there are various optical sensors such as chlorophyll content meters, namely, Soil Plant Analysis Development (SPAD) 502 plus (Konika Minolta® Inc., Tokyo, Japan) and atLEAF (FT Green LLC®, Wilmington, DE, USA), and hand-held canopy reflectance sensors such as GreenSeeker (Trimble Inc., Sunnyvale, CA, USA) and Crop Circle (Holland Scientific® Inc., Lincoln, NE, USA) which have been developed during recent years (Singh and Ali, 2020). These optical sensors measure the visible and near infrared radiations, which are absorbed and reflected from crop canopies and expressed as Normalized Difference Vegetative Index (NDVI). All these optical sensors work through principal of proximal sensing, when placed over the leaves or at a height of two meters from the canopy for prediction of vegetative index that guides to optimize the N application during mid-season (Singh *et al.* 2023). The present review emphasizes the usage of optical sensors and their application in major cereal crops for optimization of N requirement by adopting variable rate applications.

Importance and role of nitrogen in plants

Nitrogen plays an essential role in agriculture in enhancing the crop productivity and food supply (Singh *et al.* 2023). Many crops, including cereals, depend on nitrogen for growth, development and yield. For increasing plant growth, nitrogen is a vital nutrient that enhances plant biomass by stimulating cell division and elongation (Luo *et al.* 2020). Nitrogen is crucial component of chlorophyll, the pigment in charge of absorbing light energy during photosynthesis (Toth *et al.* 2002). Nitrogen is responsible for vegetative growth, improving the leaf area index, chlorophyll synthesis, and so on; thus, increasing photosynthesis and assimilate production in plants. N is deficient in most of the rice-growing areas, which requires a proper focus on nitrogen nutrition (Fageria and Baligar, 2013; Muhammad *et al.* 2021; Shankar *et al.* 2021). In cereals, nitrogen is essential component for protein synthesis (Wan *et al.* 2023). Nitrogen fertilizer affects the nitrogen metabolism enzyme and the key regulatory factors, which further regulate grain storage protein synthesis, and this induces the balance changes of grain storage substances and further regulates the grain quality (Wang *et al.* 2021).

When N content of soil rises, the aboveground crop biomass normally increases. On the other hand, if N supply in soil is insufficient to meet the crop demand, biomass may decrease due to N deficiency. N accumulated in crop biomass is divided into grain and stover. Under excess supply of N to cereals may lead to yield decrease because of improper conversion of source to sink with luxury N intake (Krupnik *et al.* 2004). During the reproductive stage of crops, an adequate N supply encourages the synthesis of grain storage proteins in reproductive parts that may result in larger and better-quality grains (Shen *et al.* 2022). N deficiency may hamper grain filling and finally, reduce crop yield in cereals (Lemaire and Gastal, 2009). The production and grain quality of crops can be significantly impacted by the nitrogen availability (Simic *et al.* 2020). The best nitrogen fertilization practice can greatly raise the crop productivity by promoting plant growth, photosynthetic rate and dry matter accumulation and proper partitioning of assimilates (Ashraf *et al.* 2016). Additionally, nitrogen influences grain quality such protein concentration, starch composition, and nutritional value (Omar *et al.* 2022). Nitrogen shows a synergistic effect with most of the essential nutrients and its presence in optimum in soil as well as in plant tissue enhances the availability and uptake of other elements (Aulakh *et al.* 2005). By facilitating effective nutrient uptake and reducing nutrient imbalances or deficiencies, N improves plant growth and development. A balanced supply of nitrogen helps maintaining an ideal nutritional balance of the crop.

Development of optical sensors for nitrogen management in cereals

Use of optical sensors for nutrient optimization in cereal crops is a recent advancement (Singh *et al.* 2021). In the last few decades, various sensors have been developed through proximal sensing which works on absorption and reflection of light over crop canopy (Table 1). Chlorophyll meters can be used to evaluate the N status of a crop, however, there may be variance in the link between SPAD readings and leaf N content due to differences in the weight or thickness of individual leaves (Shen *et al*. 2022). Other variables that may influence on the SPAD reading of leaf N status includes crop growth stage, cultivars, environmental and stress factors because of either excess or deficit water conditions, a lack of nutrients (other than N), and pests and diseases (Padilla *et al*. 2018). Chlorophyll meter readings and leaf N status have often been found to be linearly related in most of the crops. Numerous studies have examined the use of chlorophyll meters with different crop species, mostly with cereals like maize and wheat, since they were developed for the purpose of monitoring the N status of rice in the early 1980s. The majority of studies used transmittance-based chlorophyll meters. The popularity of fluorescence-based chlorophyll meters was recently gained the popularity (Kalaji *et al*. 2018).

Generally, chlorophyll meter readings were substantially correlated with leaf and crop N contents, with better correlations being found when employed for individual cultivars in a specific region of study (Muhammad *et al*. 2021). Numerous studies were documented linear connections between crop or leaf nitrogen content and chlorophyll meter readings for measurements taken at specific times or growth stages. However, other investigations noted a plateau response, where the linear connection appears to “flatten out” at somewhat large nitrogen

Table 1: Innovation of optical sensors for precision nitrogen management

Year	Optical sensors	Reference
1992	SPAD chlorophyll meter (transmission of 650, 940 nm) for estimating crop nitrogen requirement by using threshold value	Turner and Jund, 1992
1996	Canopy reflectance sensor (reflectance of 671, 780 nm) for optimization of variability in plant nitrogen	Stone *et al.* 1996
2002	Green Seeker canopy reflectance sensor (reflectance of 650, 770 nm) for real time detection NDVI.	Raun *et al.* 2002
2004	Crop Circle canopy reflectance sensor (reflectance of 590, 880 nm or 670, 730, 780 nm)	Holland *et al.* 2004
2012	At LEAF chlorophyll content meter (transmission of 660, 940 nm)	Zhu *et al.* 2012

Source: *Zhu et al. 2012; Singh and Ali, 2020.*

concentrations. Similar plateau responses were observed at high leaf chlorophyll concentrations. There was persistent evidence that at high nitrogen and chlorophyll levels, chlorophyll meters can partially saturate (Huang *et al*. 2021). To the contrary, linear relationships between chlorophyll meter readings and leaf chlorophyll or leaf or plant nitrogen content were frequently found instead of the partial saturation response (Javaid *et al*. 2023). Wheat and maize were used in most studies. NDVI was one of the most popular vegetation indexes for crop nitrogen management (Hawkins *et al*. 2007). Proximal canopy reflectance sensors were widely used to apply variable rates of nitrogen fertilizer to cereal crops.

Chlorophyll content meters

Chlorophyll meters, which assume the relative chlorophyll concentration per unit of leaf surface area, are the first group of optical sensors to be researched to manage the topdressing of nitrogen to the crop (Monje *et al.* 1992). As most of the nitrogen in leaves is found in the enzymes and used in photosynthesis, chlorophyll is a nitrogen sensitive substance that is closely tied to the amount of nitrogen in leaves (Kim *et al.* 2006). Most of the chlorophyll meters are portable instruments that clip onto leaf or positioned near the leaf surface to obtain the greenness index (Kamarianakis and Panagiotakis, 2023). Chlorophyll meters quantify the amount of nitrogen that is closely related to the amount of chlorophyll present. Chlorophyll meters help farmers to assess and improve the management of nitrogen in plants and estimate the health of the plants by measuring the greenness of the leaves (Widjaja-putra and Soni, 2018). To determine the amount of chlorophyll present, these optical electrical instruments can measure the light that penetrates a leaf or the light that is reflected from its surface (Moya *et al.* 2004). Commercial chlorophyll meters, however, typically cost more amount, making them inaccessible to farmers, crop researchers, and communities lacking in resources, in general, as well as growers and common citizens interested in self-cultivation (Khan *et al.* 2020). Some of the commercially available transmittance-based chlorophyll metres are T SPAD-502 and N-tester, which are nearly identical, the more recent and affordable at LEAF+ sensor, or the MC-100 Chlorophyll Concentration Metre are a low-cost chlorophyll metre based on light-to-voltage measurements of the leftover light after two LED light emissions passed through a leaf is conceived, built, evaluated, and compared against the chlorophyll index (Padilla *et al.* 2018).

Further, it was proposed that SPAD meter readings might be utilized to estimate the fertilizer N requirements of cereal crops because they had a strong correlation with the rate of applied fertilizer N and leaf N concentration (Wan *et al.* 2022). SPAD meter accurately predicts the response of fertilizer N with lower error rate compared to N determination in leaf samples. There is a key SPAD value also called as threshold values for most of the cereal crops, that may be used to differentiate between responsive and non-responsive locations, and as a result, SPAD metres can be used to determine whether to apply or not to apply N fertiliser (Ali, 2020). There are two types of radiations used in chlorophyll meters such as red radiation which is absorbed by the chlorophyll and another one is near infrared (NIR) radiation, which is transmitted by the chlorophyll (Fox *et al.* 2008). Higher chlorophyll metre value results in increased red radiation absorption as chlorophyll concentration rises (Hu *et al.* 2011). The ratio of the chlorophyll fluorescence emission of red and far-red radiation is a different method of determining the relative leaf chlorophyll content (Yang *et al.* 2020). The ratio of red to far-red chlorophyll fluorescence is mostly dependent on the chlorophyll content; as chlorophyll content increases, this ratio falls due to red chlorophyll fluorescence being reabsorbed by the leaf (Buschmann, 2007). Fluorescence-based chlorophyll metres are the name given to the sensors that make use of this strategy. The Multiplex sensor such as Dualex is one such example with is having a potential use in crop nitrogen management fluorescence index (Tremblay *et al.* 2012). There are currently a number of commercially available chlorophyll metres, and they vary from each other in terms of different measuring principles that is transmittance versus fluorescence, the wavelengths used, the measurement units, and the calibration equations used to transform electrical signals into measurement units (Taskos *et al.* 2015). Comparisons between measurements taken with various chlorophyll metres are made more difficult by this diversity of methods. Numerous investigations revealed that there were significant curvilinear connections between chlorophyll metre readings and the extractable chlorophyll concentration readings at high chlorophyll content (Uddling *et al.* 2007). The chlorophyll meter readings are unit less and exposed to large changes because of variables other than nitrogen status (Zhang *et al.* 2022). As a large portion of the nitrogen in leaves is found in chlorophyll metres such as the SPAD metre, have found useful in predicting the need for supplemental nitrogen in cereals like rice, maize, and wheat. There are differences with regard to the methods for assessing the N status of leaves using chlorophyll metres on which leaf to measure and which area of the particular leaf should be measured to estimate leaf N status from crop to crop. For example, in maize, during early vegetative stage, the readings are recorded from uppermost leaf (Ziadi *et al.* 2008). After the crop reached the tasselling stage in maize, readings with a SPAD metre were taken from the ear leaf (Hawkins *et al.* 2007). However, after silk emergence, chlorophyll N content in the first fully expanded maize leaf from the top was decreased. But the ear leaf's chlorophyll concentration, either increased or remained constant in middle leaves (Singh *et al.* 2021). Additionally, SPAD measurements in maize and have been done at one-quarter, two-thirds, or halfway between the leaf tip and the stalk from the leaf tip towards the stem. Similarly in rice, it is standard practise to collect SPAD measurements on the topmost fully expanded leaf to determine the leaf's N status. Additionally, it has been recorded that lower leaf SPAD values have a stronger correlation with the total N in the plant's leaves (Singh *et al.* 2021). Therefore, the lower, biologically older leaves' SPAD readings were more responsive to fertiliser N rates than the top, younger leaves.

Crop reflectance sensors

The use of proximate reflectance sensors such as green seeker has been subjected to extensive research over past two decades for crop nitrogen management (Diacono *et al.* 2013). The visible and NIR spectral reflectance from plant canopies is measured by canopy reflectance sensors, and the results are interpreted in terms of nitrogen stress (Daughtry *et al.* 2000). Between 70% and 90% of all incident light in the red wavelength bands is absorbed by the chlorophyll found in leaves, which controls the reflectance of visible light (Gitelson *et al.* 2003). The structure of mesophyll tissues controls the reflectance upto 60% of the incident NIR radiation (Xu and Ye *et al.* 2023). By monitoring wavelengths of radiation absorbed and reflected from foliage of the crop, reflectance sensors can provide information on the crop's nitrogen status. Sensors are placed quite close to the crop in the proximal canopy reflectance i.e., 0.4–3.0 m from the crop canopy (Singh *et al.* 2021). When compared to N-sufficient crops to N-deficient crops, the N-deficient crops typically reflect more visible light and less NIR light. Wavelengths chosen for N assessment were picked because of their sensitivity in changing the biomass, leaf density, and chlorophyll status that come along with N deprivation (Kalaji *et al.* 2018). Based on their importance, these typically categorized into four distinct narrow bands and they are 675 nm (red absorption maxima), 905 nm (NIR reflection peak), 720 nm (mid-section of the red-edge), and 550 nm (green reflectance maxima) (Ulissi *et al.* 2011). The calculation of spectral vegetation indices, which include spectrum reflectance from 2-3 wavelengths, increases the sensitivity to a particular biophysical parameter and decreases variability (Zeng *et al.* 2022). Probably, the most popular is the Normalized Difference Vegetation Index (NDVI) (Huang *et al.* 2021). There are several indices that can differentiate between vegetation and soil, such as the Soil Adjusted Vegetation Index (SAVI), although the simple ratio indices and many normalized indices must be assessed directly on the crop canopy (Rhyma *et al.* 2020).

Depending on their own light source, reflectance sensors are of two types, namely, passive sensors and active sensors (Kipp *et al.* 2014). The majority of passive sensors have two sets of photodetectors, one measures incident radiation above the crop canopy and the other detects radiation reflected from the canopy (Loayza *et al.* 2023). The sensor uses the measurement of incident radiation to take various irradiance circumstances into account when in use. Modern active sensors have a light source that produces both NIR and visible light. Active sensors can be employed in all irradiance situations because they can discriminate between reflected radiation from their own light source and that obtained from ambient radiation by regulating the light source (Akselrod *et al.* 2006). The active sensors include several Crop Circle and GreenSeeker sensors, as well as the N-Sensor ALS (Erdle *et al.* 2011). The Crop Circle and GreenSeeker sensors are available in a variety of models, with simpler, less expensive, and hand-held versions that are ideal for manual use with cereal crops (Samborski *et al.* 2009). The more costly types can typically be used for continuous data collection, for which they are frequently installed on tractors and connected to GPS systems for field mapping (Waqas *et al.* 2023). The application of mineral fertilizer at an automatic variable rate is the primary use for field installed crop canopy sensors.

Fertilizer N management using chlorophyll content meters

Chlorophyll meter is used to monitor status of nitrogen in the crop and increase nitrogen use efficiency (Yadav *et al.* 2017). The management of nitrogen fertilizer in crops can be done using at two different types of portable chlorophyll meters. The most popularly used is Soil Plant Analysis Development (SPAD) 502 Plus chlorophyll meter that measures chlorophyll concentration by measuring light transmittance through the leaf at 650 and 940 nm (Putra, 2020); while the SPAD meter utilizes a wavelength of 650 nm. The recently developed at LEAF chlorophyll meter uses 660 nm wavelength. Readings from an at LEAF chlorophyll meter are comparable to those from a SPAD meter, although the at LEAF chlorophyll meter is less expensive (Brown *et al.* 2022). Most of the research covered using of hand-held Minolta SPAD-502 chlorophyll meter, which continues to be the most used chlorophyll meter for nitrogen management in cereals (Bana, *et al.* 2020). N-Tester, is one of the modified SPAD-502 chlorophyll meter, mostly used in Europe to manage nitrogen fertilizer in field crops (Arregui *et al.* 2006).There are two main categories of research aimed to enhancing N use efficiency with chlorophyll meters: (i) establishing and evaluating the association between chlorophyll meter readings and the nitrogen content of leaves; and (ii) determining the relationship between chlorophyll meter readings and the fertilizer N dosages to be top dressed in field crops (Zhu *et al.* 2012).

Fertilizer N management using crop canopy reflectance sensors

For precise N management, estimation of nitrogen status in crops is essential. There are various crop reflectance sensors available to estimate the greenness index of the crop. GreenSeeker is one of the mostly used crop reflectance sensor to estimate the relative greenness of the leaf which was given as NDVI. The Crop growth status reflects soil nitrogen availability and crop nitrogen demand (Li *et al.* 2010). Therefore, the nitrogen need of the crop is frequently determined using estimates of the projected yield. Based on the anticipated yield and crop N status, active canopy reflectance sensors can aid in determining the nitrogen rate for fertilizer during the growing season (Siqueira *et al.* 2022). For an algorithm to easily understand sensor measures in terms of the crop's need for fertilizer N at the sensed growth stage, relationships between sensor measurements and crop N status as well as projected yield of the crop must be created. For non-invasive ways to optimize nitrogen fertilization and to lower the environmental concerns related to improper use of fertilizer N, the precise prediction of N uptake is crucial (Xiong *et al.* 2019).

Use of Absolute Sufficiency Values for Crop N Management

Utilising the absolute sufficiency values of optical sensor measurements is an alternate method to get over the drawback of reference plots in the absence of saturation (Pacifici *et al.* 2008). Absolute sufficiency values for sensor measurements make a distinction between deficiency (below the value), sufficiency (around the value), and excess (above the value) (De Souza *et al.* 2019). Absolute sufficiency values have often been calculated using two methods: (i) yield response, and (ii) crop nitrogen status (Gianquinto *et al.* 2006). Absolute sufficiency values can be connected to the cumulative thermal time and phenological phases to offer flexibility regarding planting dates, cropping cycles, and location (Padilla *et al.* 2015). The use of optical sensors is facilitated by sufficiency values for phenological stages since measurements may be linked to clearly distinguishable crop development stages (Liebisch *et al.* 2015). The drawback of using chronological age is that it ignores variations in crop development brought on by various growing environments during each crop cycle. The uncomplicated management of crop N may be made easier using absolute sufficiency values (Ransom *et al.* 2019). Adjustments to N fertiliser management should be performed as soon as optical readings depart from absolute sufficiency levels to account for suboptimal crop N status. This can be accomplished using a semi-quantitative method by making modifications (adding more or less N) to an earlier schedule of N fertiliser applications (Vaccaro, 2023). This scenario serves as an illustration of prescriptive-corrective N management. The cultivar and growing circumstances may have an impact on how absolute sufficiency measurements are used for crop N management with optical sensors (Solie *et al.* 2012). To validate sufficiency values with various cultivars and growing conditions, additional research is need to be carried out with crop and climate specific conditions for better precision of nitrogen application.

Limitations on application of smart tools in Indian agriculture

There are still several restrictions that need to be considered when using smart precision nutrition tools in India, even though smart tools and technology have the potential to revolutionize many things in agriculture (Bhat and Huang, 2021). A fundamental obstacle to the widespread use of smart tools in agriculture is the lack of straight forward solutions. Smart tools have a high initial investment. Small-scale farmers, especially those in developing nations like India, may find it difficult to invest in the costly machinery or technologies needed for smart farming (Mizik, 2023). Many farmers may find the cost of sensors and other smart equipment to be expensive, which hinders their adoption for best performance. Further, a smart equipment frequently needs a dependable internet connection (Qu *et al.* 2022). However, in rural locations, poor connectivity may obstruct real-time data transfer, which is necessary for smart instruments to function effectively. In the developing countries, most of the farmers do not have digital expertise to independently work with smart tools. Farmers lack technical understanding and are ignorant of such technology, especially those in rural areas. The latest farming technologies in agriculture may flourish as knowledge grows and technologies are more readily available to the common farmer with smart tools driving the change (Javaid *et al.* 2023). Farmers must possess a particular level of technical knowledge and proficiency to successfully deploy smart instruments in crop production (Srivetbodee and Igel, 2021). For farmers who are unfamiliar with the technology or do not have access to training programmes, that can be a barrier to technology transfer (Kuhl, 2020).

CONCLUSION

Over use of fertilizers like nitrogen can result in various problem associated to soil degradation, contamination of water bodies through nitrate accumulation and volatilization of ammonia in to atmosphere. Optimization of fertilizer nitrogen can be easily achieved by site-specific approach. Variable rate application by using optical sensors can be an alternative for blanket application in which the required amount of nitrogen can be applied in more splits as per the crop requirement. Application of optimized amount of nitrogen in more splits can be more productive in terms of crop growth and productivity than compared with excess application of nitrogen. The hand-held optical sensors can provide the real time plant nitrogen status in an instant manner which can help crop growers to apply the nitrogen in a précised manner at the critical time of crop requirement.

REFERENCES

Akselrod, M.S., Bøtter-Jensen, L. and McKeever, S.W.S. 2006. Optically stimulated luminescence and its use in medical dosimetry. *Radiation Measurements*, **41**: S78-S99.

Ali, A.M. 2020. Using hand-held chlorophyll meters and canopy reflectance sensors for fertilizer nitrogen management in cereals in small farms in developing countries. *Sensors*, **20**(4): 1127.

Arregui, L.M., Lasa,B., Lafarga, A., Irañeta, I., Baroja, E. and Quemada, M. 2006. Evaluation of chlorophyll meters as tools for N fertilization in winter wheat under humid Mediterranean conditions. *Eu. J. Agron.*, **24**(2): 140-148.

Ashraf, U., Salim, M.N., Alam, S., Aqil, K., Shenggang, P. and Xiangru, T. 2016. Maize growth, yield formation and water-nitrogen usage in response to varied irrigation and nitrogen supply under semi-arid climate. *Turkish J. Field Crops*, **21**(1): 88-96.

Aulakh, M.S. and Malhi, S.S. 2005. Interactions of nitrogen with other nutrients and water: Effect on crop yield and quality, nutrient use efficiency, carbon sequestration and environmental pollution. *Adv. in Agron.*, **86**: 341-409.

Bana, R.C., Yadav, S.S., Shivran, A.C., Singh, P. and Kudi, V.K. 2020. Site-specific nutrient management for enhancing crop productivity. *Int. Res. J. Pure and Appl. Chemi.*, **21**(15): 17-25.

Bhat, S.A. and Huang, N.F. 2021. Big data and ai revolution in precision agriculture: Survey and challenges. *IEEE Access*, **9**: 110209-110222.

Brown, L.A., Williams, O. and Dash, J. 2022. Calibration and characterisation of four chlorophyll meters and transmittance spectroscopy for non-destructive estimation of forest leaf chlorophyll concentration. *Agril. and Forest Meteorology*, **323**: 7 109059.

Buschmann, C. 2007. Variability and application of the chlorophyll fluorescence emission ratio red/far-red of leaves. *Photosynthesis Res.*, **92**: 261-271.

Daughtry, C.S., Walthall, C.L., Kim, M.S., De Colstoun, E.B. and McMurtrey Iii, J.E. 2000. Estimating corn leaf chlorophyll concentration from leaf and canopy reflectance. *Remote Sensing of Environ.*, **74**(2): 229-239.

De Souza, R., Peña-Fleitas, M.T., Thompson, R.B., Gallardo, M., Grasso, R. and Padilla, F.M. 2019. The use of chlorophyll meters to assess crop N status and derivation of sufficiency values for sweet pepper. *Sensors*, **19**(13): 2949.

Diacono, M., Rubino, P. and Montemurro, F. (2013). Precision nitrogen management of wheat. A review. *Agronomy for Sustainable Development*, **33**: 219-241.

Diacono, M., Rubino, P. and Montemurro, F. 2013. Precision nitrogen management of wheat. A review. *Agronomy for Sustainable Development*, **33**: 219-241.

Erdle, K., Mistele, B. and Schmidhalter, U. 2011. Comparison of active and passive spectral sensors in discriminating biomass parameters and nitrogen status in wheat cultivars. *Field Crops Research*, **124**(1):74-84.

Fageria, N.K. and Baligar, V.C. 2013 Methodology for evaluation of lowland rice genotypes for nitrogen use efficiency. *J. Plant Nutrition*, **26**: 1315–1333.

Fox, R.H., Walthall, C.L. 2008. Crop monitoring technologies to assess nitrogen status. In Nitrogen in Agricultural Systems, Agronomy Monograph No. 49; Schepers, J.S., Raun, W.R., Eds., American Society of Agronomy, Crop Science Society of America, Soil Science Society of America: Madison, WI, USA, 2008, pp. 647–674.

Gianquinto, G., Sambo, P., Borsato, D. 2006. Determination of SPAD threshold values for the optimisation of nitrogen supply in processing tomato. *Acta Hortic.*, **700**:159–166.

Gitelson, A.A., Gritz, Y. and Merzlyak, M.N. 2003. Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves. *J. Plant Physiology*, **160**(3): 271-282.

Hawkins, J.A., Sawyer, J.E., Barker, D.W. and Lundvall, J.P. 2007. Using relative chlorophyll meter values to determine nitrogen application rates for corn. *Agronomy Journal*, **99**: 1034–1040.

Holland, K.H., Schepers, J.S., Shanahan, J.F. and Horst, G.L. 2004. Plant canopy sensor with modulated polychromatic light. In Proceedings of the 7th International Conference on Precision Agriculture, Minneapolis, MN, USA.

Hu, J., He, D. and Yang, P. 2011. Study on plant nutrition indicator using leaf spectral transmittance for nitrogen detection. *Advances in Infrastructure and Communication Technology*, **347**: 504–513.

Huang, S., Tang, L., Hupy, J. P., Wang, Y. and Shao, G. 2021. A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *J. Forestry Res.*, **32**(1): 1-6.

Javaid, M., Haleem, A., Khan, I.H. and Suman, R. 2023. Understanding the potential applications of Artificial Intelligence in Agriculture Sector. *Adv. Agrochem.*, **2**(1): 15-30.

Kalaji, H.M., Bąba, W., Gediga, K., Goltsev, V., Samborska, I. A., Cetner, M. D. and Kompała-Bąba, A. 2018. Chlorophyll fluorescence as a tool for nutrient status identification in rapeseed plants. *Photosynthesis Res.*, **136**: 329-343.

Kamarianakis, Z. and Panagiotakis, S. 2023. Design and Implementation of a Low-Cost Chlorophyll Content Meter. *Sensors*, **23**(5): 2699.

Khan, N., Fahad, S., Naushad, M. and Faisal, S. 2020. Economics of Agriculture in the World. *Available at SSRN 3603274*.

Kim, S.H., Sicher, R.C., Bae, H., Gitz, D.C., Baker, J.T., Timlin, D.J. and Reddy, V.R. 2006. Canopy photosynthesis, evapotranspiration, leaf nitrogen and transcription profiles of maize in response to CO_2 enrichment. *Global Change Biology*, **12**(3): 588-600.

Kipp, S., Mistele, B. and Schmidhalter, U. 2014. The performance of active spectral reflectance sensors as influenced by measuring distance, device temperature and light intensity. *Computers and Electronics in Agric.*, **100**: 24-33.

Krupnik, T.J., Six, J., Ladha, J.K., Paine, M.J., and van Kessel, C. 2004. An Assessment of Fertilizer Nitrogen Recovery Efficiency by Grain Crops Across Scales. *In:* Mosier, A.R., Syers, K.J. and Freney, J.R. (eds.) Agriculture and the Nitrogen Cycle, The Scientific Committee Problems of the Environment. Island Press, Covelo, California, USA, pp.193-207.

Kuhl, L. 2020. Technology transfer and adoption for smallholder climate change adaptation: opportunities and challenges. *Climate and Dev.*, **12**(4): 353-368.

Kumar, P.P., Shankar, T., Maitra, S., Ram, M.S. and Bhavana, T., 2022. Effect of nutrient omission on growth and productivity of maize (*Zea mays* L.). *Crop Res.*, **57**(3): 128-135.

Lemaire, G. and Gastal, F. 2009. Quantifying Crop Responses to Nitrogen Deficiency and Avenues to Improve Nitrogen Use Efficiency. *Crop Physiology*, pp. 171–211.

Li, Y., Chen, D., Walker, C.N. and Angus, J.F. 2010. Estimating the nitrogen status of crops using a digital camera. *Field Crops Res.*, **118**(3): 221-227.

Liebisch, F., Kirchgessner, N., Schneider, D., Walter, A. and Hund, A. 2015. Remote, aerial phenotyping of maize traits with a mobile multi-sensor approach. *Plant Methods*, **11**(1): 1-20.

Loayza, H., Moya, I., Quiroz, R., Ounis, A. and Goulas, Y. 2023. Active and passive chlorophyll fluorescence measurements at canopy level on potato crops. Evidence of similitude of diurnal cycles of apparent fluorescence yields. *Photosynthesis Res.*, **155**(3): 271-288.

Luo, L., Zhang, Y. and Xu, G. 2020. How does nitrogen shape plant architecture? *J. Experimental Bot.*, **71**(15): 4415-4427.

Mizik, T. 2023. How can precision farming work on a small scale? A systematic literature reviews. *Precision Agric.*, **24**(1): 384-406.

Monje, O.A. and Bugbee, B. 1992. Inherent limitations of nondestructive chlorophyll meters: A comparison of two types of meters. *Horticultural Science*, **27**: 69–71. [PubMed]

Moya, I., Camenen, L., Evain, S., Goulas, Y., Cerovic, Z.G., Latouche, G. and Ounis, A. 2004. A new instrument for passive remote sensing: 1. Measurements of sunlight-induced chlorophyll fluorescence. *Remote Sensing of Environ.*, **91**(2): 186-197.

Muhammad, I., Shalmani, A., Ali, M., Yang, Q.H., Ahmad, H. and Li, F.B. 2021. Mechanisms regulating the dynamics of photosynthesis under abiotic stresses. *Frontiers in Plant Sci.*, **11**: 615942.

Nduwimana, D., Mochoge, B., Danga, B., Cargele Masso, C., Maitra, S and Gitari, H. 2020. Optimizing nitrogen use efficiency and maize yield under varying fertilizer rates in kenya. *Int. J. Bioresource Sci.*, 7(2): 63-73.

Omar, S., Abd Ghani, R., Khaeim, H., Sghaier, A. H. and Jolánkai, M. 2022. The effect of nitrogen fertilisation on yield and quality of maize (*Zea mays* L.). *Acta Alimentaria*, **51**(2): 249-258.

Pacifici, F., Del Frate, F., Emery, W.J., Gamba, P. and Chanussot, J. 2008. Urban mapping using coarse SAR and optical data: Outcome of the 2007 GRSS data fusion contest. *IEEE Geoscience and Remote Sensing Letters*, **5**(3): 331-335.

Padilla, F.M., Gallardo, M., Peña-Fleitas, M.T., De Souza, R. and Thompson, R.B. 2018. Proximal optical sensors for nitrogen management of vegetable crops: A review. *Sensors*, **18**(7): 2083.

Padilla, F.M., Peña-Fleitas, M.T., Gallardo, M. and Thompson, R.B. 2015. Threshold values of canopy reflectance indices and chlorophyll meter readings for optimal nitrogen nutrition of tomato. *Annals of Appl. Biology*, **166**: 271-285.

Putra, B.T.W. 2020. New low-cost portable sensing system integrated with on-the-go fertilizer application system for plantation crops. *Measurement*, **155**: 107562.

Qu, C., Boubin, J., Gafurov, D., Zhou, J., Aloysius, N., Nguyen, H. and Calyam, P. 2022. UAV swarms in smart agriculture: Experiences and opportunities. In *2022 IEEE 18th Int. Conference on e-Science (e-Science)* (pp. 148-158). IEEE.

Ram, M.S., Shankar, T., Maitra, S. and Duvvada, S.K. 2020. Effect of Integrated Nutrient Management on Growth, Yield, Nutrient Content and Economics of Summer Rice (Oryza sativa L.). *Indian J. Pure and Appl. Biosciences*, **8**(3): 421-427.

Ransom, C.J., Kitchen, N.R., Camberato, J.J., Carter, P.R., Ferguson, R.B., Fernández, F.G. and Shanahan, J.F. 2019. Statistical and machine learning methods evaluated for incorporating soil and weather into corn nitrogen recommendations. *Computers and Electronics in Agric.*, **164**: 104872.

Raun, W.R., Solie, J.B., Johnson, G.V., Stone, M.L., Mullen, R.W., Freeman, K.W., Thomason, W. and Lukina, E.V. 2002. Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. *Agron. J.*, **94**: 815–820.

Rhyma, P.P., Norizah, K., Hamdan, O., Faridah-Hanum, I. and Zulfa, A.W. 2020. Integration of normalised different vegetation index and Soil-Adjusted Vegetation Index for mangrove vegetation delineation. *Remote Sensing Applications: Society and Environment*, **17**: 100280.

Sairam, M., Maitra, S., Praharaj, S., Nath, S., Shankar, T., Sahoo, U., Santosh, D.T., Sagar, L., Panda, M., Shanthi Priya, G. and Ashwini, T.R., 2023. An Insight Into the Consequences of Emerging Contaminants in Soil and Water and Plant Responses. In *Emerging Contaminants and Plants: Interactions, Adaptations and Remediation Technologies* (pp. 1-27). Cham: Springer International Publishing.

Samborski, S.M., Tremblay, N. and Fallon, E. 2009. Strategies to make use of plant sensors-based diagnostic information for nitrogen recommendations. *Agron. J.*, **101**(4): 800-816.

Shankar, T., Maitra, S., Ram, M.S. and Mahapatra, R. 2020. Influence of integrated nutrient management on growth and yield attributes of summer rice (*Oryza sativa* L.). *Crop Res.*, **55**(1and2): 1-5.

Shankar, T., Malik, G.C., Banerjee, M., Dutta, S., Maitra, S., Praharaj, S., Sairam, M., Kumar, D.S., Dessoky, E.S., Hassan, M.M., Ismail, I.A., Saif, T., Skalicky, M, Brestic, M. and Hossain, A. 2021. Productivity and Nutrient Balance of an Intensive Rice–Rice Cropping System Are Influenced by Different Nutrient Management in the Red and Lateritic Belt of West Bengal, India. *Plants*, **10**: 1622.

Shen, S., Ma, S., Chen, X.M., Yi, F., Li, B.B., Liang, X.G. and Ruan, Y.L. 2022. A transcriptional landscape underlying sugar import for grain set in maize. *The Plant J.*, **110**(1): 228-242.

Simić, M., Dragičević, V., Mladenović Drinić, S., Vukadinović, J., Kresović, B., Tabaković, M. and Brankov, M. 2020. The contribution of soil tillage and nitrogen rate to the quality of maize grain. *Agron.*, **10**(7): 976.

Singh, B, and Ali, M.A. 2020. Using hand-held chlorophyll meters and canopy reflectance sensors for fertilizer nitrogen management in cereals in small farms in developing countries. *Sensors*, **20**(4): 1127.

Singh, B. 2018. Are nitrogen fertilizers deleterious to soil health? *Agron.*, **8**(4): 48.

Singh, H., Halder, N., Singh, B., Singh, J., Sharma, S. and Shacham-Diamand, Y. 2023. Smart farming revolution: portable and real-time soil nitrogen and phosphorus monitoring for sustainable agriculture. *Sensors*, **23**(13): 5914.

Singh, v., Kunal, Bentley, A.R., Griffiths, H., Barsby, T. and Bijay-Singh. 2021. Optical Sensors for Rational Fertilizer Nitrogen Management in Field Crops. *In*: Bhatt, R., Meena, R.S., Hossain, A. (eds.) *Input Use Efficiency for Food and Environmental Security*. Springer, Singapore.

Siqueira, R., Mandal, D., Longchamps, L. and Khosla, R. 2022. Assessing nitrogen variability at early stages of maize using mobile fluorescence sensing. *Remote Sensing*, **14**(20): 5077.

Solie, J.B., Monroe, A.D., Raun, W.R. and Stone, M.L. 2012. Generalized algorithm for variable-rate nitrogen application in cereal grains. *Agron. J.*, **104**(2): 378-387.

Srivetbodee, S. and Igel, B. 2021. Digital technology adoption in agriculture: Success factors, obstacles and impact on corporate social responsibility performance in Thailand's smart farming projects. *Thammasat Rev.*, **24**(2): 149-170.

Stone, M.L., Solie, J.B., Raun, W.R., Whitney, R.W., Taylor, S.L. and Ringer, J.D. 1996. Use of spectral radiance for correcting in-season fertilizer nitrogen deficiencies in winter wheat. *Transactions of ASAE*, ***39***: 1623–1631.

Taskos, D.G., Koundouras, S., Stamatiadis, S., Zioziou, E., Nikolaou, N., Karakioulakis, K. and Theodorou, N. 2015. Using active canopy sensors and chlorophyll meters to estimate grapevine nitrogen status and productivity. *Precision Agric.*, **16**: 77–98.

Tóth, V.R., Mészáros, I., Veres, S. and Nagy, J. 2002. Effects of the available nitrogen on the photosynthetic activity and xanthophyll cycle pool of maize in field. *J. Plant Physiology*, **159**(6): 627-634.

Tremblay, N., Wang, Z. and Cerovic, Z.G. 2012. Sensing crop nitrogen status with fluorescence indicators. A review. *Agron. for Sustainable Dev.*, **32**: 451-464.

Turner, F.T. and Jund, M.F. 1991. Chlorophyll meter to predict nitrogen top dress requirement for semidwarf rice. *Agron. J.*, *83*: 926–928.

Uddling, J., Gelang-Alfredsson, J., Piikki, K. and Pleijel, H. 2007. Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. *Photosynthesis Res.*, **91**: 37–46.

Ulissi, V., Antonucci, F., Benincasa, P., Farneselli, M., Tosti, G., Guiducci, M., Tei, F., Costa, C., Pallottino, F. snd Pari, L. 2011. Nitrogen concentration estimation in tomato leaves by VIS-NIR non-destructive spectroscopy. *Sensors*, **11**: 6411–6424.

Vaccaro, C. 2023. Environmental and Biological Implications for Understorey Crop Growth in Temperate Silvoarable Agroforestry Systems (Doctoral dissertation, ETH Zurich).

Wan, C., Gao, L., Wang, J., Lei, X., Tao, J., Feng, B. and Jinfeng G. 2023. Effects of nitrogen fertilizer on protein synthesis, accumulation, and physicochemical properties in common buckwheat. *The Crop J.*, **11**(3): 941-950.

Wan, W., Zhao, Y., Xu, J., Liu, K., Guan, S., Chai, Y. and Diao, M. 2022. Reducing and delaying nitrogen recommended by leaf critical SPAD value was more suitable for nitrogen utilization of spring wheat under a new type of drip-irrigated system. *Agron.*, **12**(10): 2331.

Wang. X., Wang, K., Yin, T., Zhao, Y., Liu, W., Shen, Y., Ding, Y. and Tang, S. 2021. Nitrogen Fertilizer Regulated Grain Storage Protein Synthesis and Reduced Chalkiness of Rice Under Actual Field Warming. *Frontiers in Plant Science*, **12**: 715436.

Waqas, M.M., Wasim, M., Ashraf, M. and Jatoi, W.N. 2023. Engineering Principles of Precision Farming: Pathway for the Developing Countries to Ensure Food Security. In *Climate Change Impacts on Agriculture: Concepts, Issues and Policies for Developing Countries* Cham: Springer International Publishing, (pp. 105-133).

Widjaja Putra, B. T. and Soni, P. 2018. Enhanced broadband greenness in assessing Chlorophyll a and b, Carotenoid and Nitrogen in Robusta coffee plantations using a digital camera. *Precision Agric.*, **19**: 238-256.

Widjaja-Putra, B.T. and Soni, P. 2018. Enhanced broadband greenness in assessing Chlorophyll a and b, Carotenoid and Nitrogen in Robusta coffee plantations using a digital camera. *Precision Agric.*, **19**: 238-256.

Xiong, X., Zhang, J., Guo, D., Chang, L. and Huang, D. 2019. Non-Invasive Sensing of Nitrogen in Plant Using Digital Images and Machine Learning for Brassica Campestris ssp. Chinensis L. *Sensors*, **19**(11): 2448.

Xu, K. and Ye, H. 2023. Light scattering in stacked mesophyll cells results in similarity characteristic of solar spectral reflectance and transmittance of natural leaves. *Scientific Reports*, **13**(1): 4694.

Yadav, M.R., Kumar, R., Parihar, C.M., Yadav, R.K., Jat, S.L., Ram, H. and Jat, M. L. 2017. Strategies for improving nitrogen use efficiency: A review. *Agric. Rev.*, **38**(1): 29-40.

Yang, P., Van der tol, C., Campbell, P.K. and Middleton, E.M. 2020. Fluorescence Correction Vegetation Index (FCVI): A physically based reflectance index to separate physiological and non-physiological information in far-red sun-induced chlorophyll fluorescence. *Remote Sensing of Environment*, **240**: 111676.

Zeng, Y., Hao, D., Huete, A., Dechant, B., Berry, J., Chen, J.M. and Chen, M. 2022. Optical vegetation indices for monitoring terrestrial ecosystems globally. *Nature Rev. Earth & Environ.*, **3**(7): 477-493.

Zhang, R., Yang, P., Liu, S., Wang, C. and Liu, J. 2022. Evaluation of the methods for estimating leaf chlorophyll content with SPAD chlorophyll meters. *Remote Sensing*, **14**(20): 5144.

Zhu, J., Tremblay, N. and Liang, Y. 2012. Comparing SPAD and atLEAF values for chlorophyll assessment in crop species. *Canadian J. Soil Sci.*, **92**: 645–648.

Ziadi, N., Brassard, M., Belanger, G., Claessens, A., Tremblay, N., Cambouris, A.N., Nolin, M.C. and Parent, L. 2008. Chlorophyll measurements and nitrogen nutrition index for the evaluation of corn nitrogen status. *Agron. J.*, **100**: 1263–1273.