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Real-Time Intelligence, Sensor-based Nitrogen Estimation for Precision N-Management in Wheat

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***Abstract*— This paper deals with the significance of precision farming in addressing challenges faced by Indianagriculture. This study aims to advance our understanding of plant sensors and their effectiveness inpredicting plant nitrogen (N) status and crop yields. It seeks to establish a reliable relationship between sensor measurements and actual leaf N content using machine learning algorithms, GreenSeeker, chlorophyll meter, and spectro-radiometer to provide a more accurate and efficient means of N management. The study focuses on variable N-fertilized wheat crops. Increments of 30kg/ha in N application rate increased SPAD values and NDVI both indices showing peak values at 150 kg N/ha. There existed a nearly linear relationship between sensor indices with leaf N content within the boundaries of selected N rates (0 -240 kg N/ha). Further, a correlation analysis of differentsensor (Chlorophyll meter, GreenSeeker) indices with leaf N content was positive and significant (R^2=0.86-0.95). Spectro-radiometer-based spectral-derived indices gave a good prediction of plant N status as indicated by an R^2 value of 0.71. Apart from these sensors, machine learning tools also revealed a very strong positive correlation (0.974) among studied parameters; the heat map generateddepicted multicollinearity, which could be considered in further analysis for the predictive model. Overall, the N stress in the wheat crop can be monitored on a real-time basis for determining the N fertilization in this crop.**

I. INTRODUCTION

A large majority of the Indian population being vegetarian meet their calorie requirements by consuming foods of plant origin or foods derived from different plants. To maintain India's self- sufficiency in food and food exports, the country is required to improve agricultural production, especially food grains. India acquired self-sufficiency in food-grain production in the period of 'The Green Revolution, which started during the late 1960s. India has witnessed a record food grain production (rice, wheat, coarse cereals, and pulses) of 329.7 million tonnes (mt) for the year 2022-23 [1]. However, several issues are constraining Indian agriculture; most importantly, low farm incomes due to rising input prices, low input-use efficiency, environmental deterioration, and climate change need greater attention from the scientists, policy makers, and development agencies concerning agriculture. To improve resource-use efficiency and reduce the environmental footprints of agriculture, precision framing offers a solution.

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Precision farming toolsand practices evaluation is mostly confined to controlled environment setups, nevertheless gradually expanding to open field conditions also.

Precision farming is defined as an integrated information and production-based farming system that is designed to increase long-term, site-specific, and whole-farm production efficiency, productivity, and profitability while minimizing unintended impacts on wildlife and the environment. Specifically, precision farming or precision agriculture is the information and communication technology-based agricultural management system to characterize, interpret, manage, and monitor spatial and temporal variability of soils, and crops within a field for profitability, sustainability, and environmental protection is a farming management concept based on observing and responding to in-field variability. Agriculture or site-specific crop management refers to the management of spatial and temporal variability at a sub-field level to improve economicreturns and reduce environmental impact. It is in-fact supplying to the desired crop the correct input,in the correct quantity, at the correct place using the correct method, and at the correct time. There are several inputs used in crop production for which precision technologies can be developed/ standardized and implemented. However fertilizer and water are the most important inputs that determine crop productivity and also the reasons for environmental pollution and climate change, thus a greater emphasis has been given to the precision application of these two key inputs over a couple of decades [2]. Among plant nutrients, N can be delivered to crops in preciseamounts and precise times using plant-N sensors, such as chlorophyll meter, GreenSeeker, spectro-radiometer, and leaf color chart (LCC) that have been shown to provide a quick assessment of plantleaf N status on a real-time mode [2] [3] [4] [5].

Generally, fertilizer management contributes more than a 50% increase in grain yield in cereal crops. Specifically, applying N fertilizers has been key to unprecedented crop yield enhancement across the globe including India [6]. Farmers need to apply large amounts of N fertilizer to crops because only 30-50% of the N is recovered due to the various losses in the soil-plant system [7]. To meet this high crop N demand, growers worldwide use about 120 million tons of N fertilizer each year [8].

Doubling of world's agricultural food production over the past four decades has been associated with a seven-fold increase in the use of N-fertilisers. Yet, over the years, widespread N- deficiency in soil has become a serious concern because 50% of the human population relies on N- fertiliser for food production. In several states of India, the use of N fertilizers is more than conventionally recommended rates though under-use of N fertilizers is also common in many states of India. Of late, there has been a serious concern about the environmental footprints of N-fertilisers, particularly in greenhouse gas emissions from agricultural fields. To meet the growing need for N-fertilisers due to the increase in food requirement of an ever-multiplying population and on the other hand to mitigate increasing environmental and atmospheric pollution, improving nitrogen-use efficiency (NUE) appears to be a viable solution. This can be done through synchronization of N-supply with the plant demand. Therefore, an accurate and quick estimation of the N content plant is important. However, laboratory methods of chemically estimating N in soil and plant samples are expensive, time and skill-intensive, and more importantly N deficiency would have already inflicted serious damages before N hunger is ascertained and matching N supply is ensured through the addition of fertilizers [4] [9]. Here, plant sensors capable of indirectly estimating plant N-status assumes greater relevance. Leaf colour chart (LCC), chlorophyll meter, GreenSeeker, and Spectro-radiometer are capable of determining plant N-status. The LCC, Chlorophyll meter and GreenSeeker are being used for precise N-scheduling in crops like, wheat, maize and rice. Scheduling N using such sensors has been shown to save 25–50% N without yield penalties [4] [6] [10]. As ascertaining N deficiency or sufficiency in plants using wet chemistry is labour, money and time- consuming exercise, thus predicting N status with plant N sensing gadgets, tools, and sensors is imperative. Thus current study has aimed to develop a reliable relationship between NDVI and SPAD values measured using GreenSeeker and chlorophyll meter with actually measured leaf N. in two staple food crops wheat. Often a simple correlation is developed and presented, between sensor indices and leaf N and crop yields. In the current paper, an attempt has been made to use machine learning algorithms and compare their efficacy with regression/correlation models currently in vogue.

II. Materials And Methods

Two leaf N sensing devices viz GreenSeeker, Chlorophyll meter, and spectro-radiometer were evaluated on wheat crop variably N-fertilized in a field experiment conducted by the Division of Agronomy, ICAR- Indian Agricultural Research Institute, New Delhi during the winter season of 2014-15. There were seven levels of N (0, 30, 60, 90, 120, 150, 180, 240 kg N/ha) application replicated three times. The field experimental site is located at a latitude of 28◦28' N and longitude of 77◦09' E and an altitude of of 228.6 m above mean sea level.

The climate of the study site is subtropical and semi-arid type; summers are dry and hot and winters are cool, sometimes, temperatures approaching 0◦C. The mean rainfall is about 650 mm of which 80% occurs during rainy months July-September. A few showers are received during the winter and spring months. Soils are sandy loam with medium to high soil fertility. Soil reaction is towards the alkaline side with a pH of 8.1. The crop was planted during the first week of December. There were a total of 21 experimental plots. The nitrogen was applied in three splits, 50% basal at the time of sowing, and the remaining half was applied in two equal splits. The first split was applied at tillering and the second at the booting stage. The NDVI values and SPAD values were measured four times during the crop period, starting from the tillering to the flowering stage. The NDVI of wheat in individual plots was measured using a handheld GreenSeeker. The GreenSeeker was moved over crop rows carefully 60 cm above the crop. This optical sensor produces red and near-infrared light using light-emitting diodes, the light reflected off of the plant canopy is captured and measured by photodiodes fitted in the front side of the sensor head. The plant chlorophyll absorbs more of red light as source of energy to operate photosynthesis systems and reflects a larger portion of NIR light. The NDVI is calculated as NDVI = (NIR-R)/(NIR+R). Thus, NDVI is indicative of not only plants' greenness or chlorophyll content but also the plant biomass.

The SPAD values were measured using a chlorophyll meter/ SPAD meter (Minolta SPAD 502). It is a small, handheld portable device that can provide an instantaneous non-destructive reading of the crop N status. In contrast to GreenSeeker, the SPAD meter takes into account the transmission of red light (wavelength 650 nm), at which chlorophyll absorbs light, and the transmission of infrared light (wavelength of 940 nm), which is not absorbed by the leaf. The leaves with higher greenness will absorb more of red light allowing its least transmission, thus indicating a higher N level. Apart from reflectance characteristics of leaves were studied using a spectro-radiometer.

Leaf N content was measured each time on the same day the sensor values were recorded, and samples collected from the field were oven-dried, ground, and analyzed in the laboratory following the standard procedures [11]. To observe the effect of variable N rates on crop yield performance and to establish a relationship between sensor indices and crop yield, the crop yields were measured for each plot by harvesting and threshing crops from individual plots separately.

The relationships between sensor indices and N status were assessed using MS Excel. With this, exponential, linear, logarithmic, power, and polynomial equations were developed, and the best-fit equations (polynomial) with the highest coefficient of determination (R2) values were considered. Apart from this, the correlation matrix (`s`) and heatmaps were generated to visualize the correlation between different features. the heatmap is a powerful visualization tool for exploring correlations in a dataset. It allows for a quick and effective assessment of relationships between variables, helping to identify patterns and potential areas of interest for more in-depth analysis.

III. Results And Discussion

At low rate or no N application, SPAD values (Chlorophyll meter) and NDVI (GreenSeeker) decreased with progression in crop growth, while at higher N rates these sensor indices values increased up to ear emergence. With an increase in N application rate, there was an increase in SPAD values and NDVI; both indices values peaked at 150 kg N/ha, beyond which the values either did not increase or increased marginally. Generally, 120 - 150 kg N/ha is considered ideal for wheat cultivation; the SAPD values against these rates lie between 40 to 45 (Fig 1) indicating the threshold range of SPAD value to be in this range for N supply, especially during maximum tillering and booting stages when adequate N supply is essential for the wheat crop. The NDVI was lowest when N application was skipped indicating N stress and increased at the highest rate up to 60 kg N/ha, further increased at a lower rate peaking at 150 -180 kg N ha whence it almost stabilized (Fig 2). There was a nearly linear relationship between sensor indices with leaf N content within the boundaries of selected N rates. Further, a correlation analysis of different sensor (Chlorophyll meter, GreenSeeker) indices with leaf N content was positive and significant (R2=0.86-0.95) (Table 1). N-stress could also be potentially monitored using the spectral signatures of wheat crops recorded using a radio-spectrometer. Different spectral derived indices were evaluated for plant N-content estimation which, in turn, indicates plant N stress. The indices gave a good prediction of plant N status as indicated by an R2 value of 0.71. Both grain and straw yields showed an upward trend with an increase in N rate though the increase in grain yield was up to 150 kg N/ha beyond which grain yield started diminishing. However, straw yield increased up to 240 kg N/ha. Both yields showed a positive and significant correlation with N- supply rates, the response of yields to N-supply was a typical polynomial. (Fig 4). Thus raising the N application rate beyond 150 kg N /ha was not of much consequence as far as grain yield is concerned.

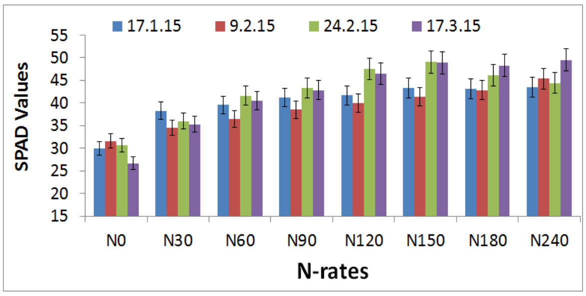


Fig 1. Periodical SPAD values of wheat leaves measured using a chlorophyll meter under variable N supply

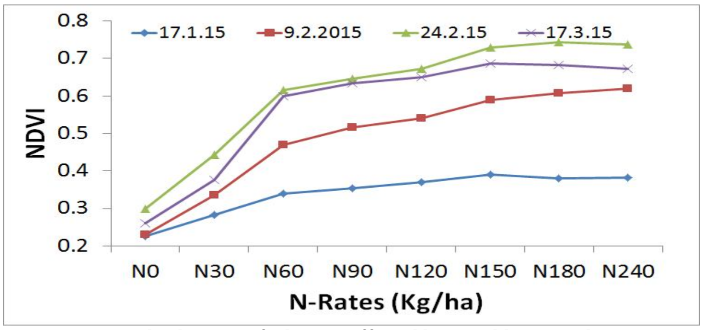
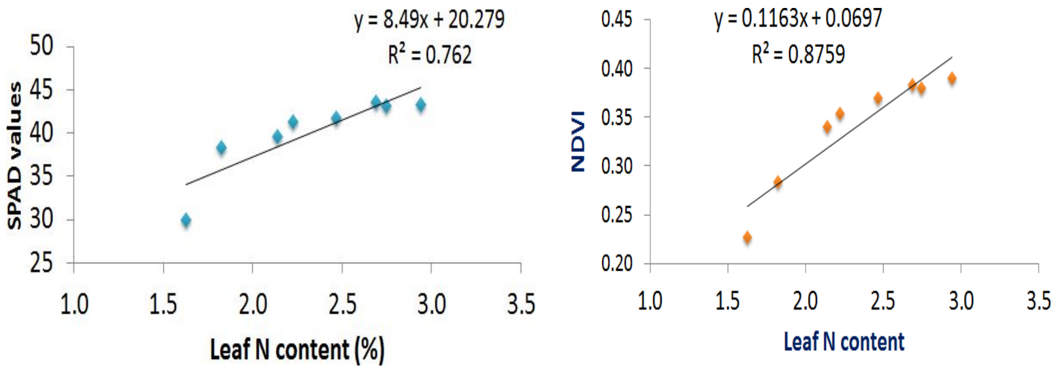


Fig 2. Periodical NDVI of wheat as affected by variable N supply



A. B.

Fig. 3 Relationship between sensor indices A. SPAD values and B. NDVI with leaf N content

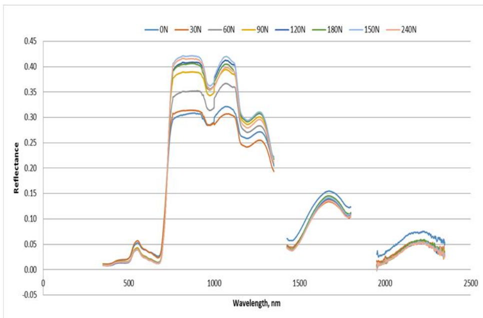


Fig. 4. Reflectance characteristics of variably N fertilized wheat

The correlation matrix shown in Fig 5 indicated that N-rates had a strong positive correlation with 'SPAD' (0.825), 'NDVI' (0.634), and 'yield' (0.816); SPAD values had a strong positive correlation with NDVI (0.827) and 'yield' (0.934); NDVI has a strong positive correlation with 'Yield' (0.716); leaf 'N Content' has a positive correlation with ' N rates (0.497), 'SPAD' (0.590), and 'NDVI' (0.614). Also, the grain yield and straw yields have a very strong positive correlation (0.974). Overall, the code provides a comprehensive overview of the dataset, including

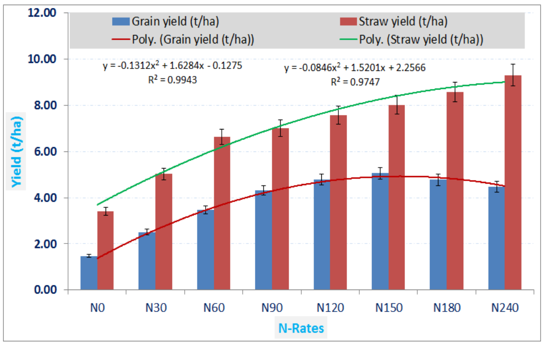


Fig. 5. Efficacy of variable N application rates on wheat yield

TABLE I CORRELATION ANALYSIS OF DIFFERENT SENSOR INDICES WITH LEAF N CONTENT

Indices /Obs. Date	17-01-2015	9-02-2015	17-03-2015
SPAD	0.871**	0.862**	0.946**
NDVI	0.942**	0.891**	0.971**

summary statistics, value counts, data types, and correlation analysis visualized through a heat-map. The strong correlations between certain features may suggest multi-co-linearity, which could be considered in further analysis for the predictive model. Also, the colours depicted in the heat map have a great significance in determining relationships among studied variables. The pale (Close to 1.0) represents a strong positive correlation between two variables. For instance, if the color is close to pale, such as between 'grain yield (yield) ' and 'straw yield (Yield)' or 'SPAD' and 'Yield_B', it indicates a strong positive linear relationship. The little darker shades of pale orange (0.7 - 0.9) reflects a moderate to strong positive correlations. Moderate shades of purple, like between 'SPAD' and 'NDVI', suggest a moderately strong positive relationship. moderate purple to bit darker purple (0.5 - 0.7) signifies a moderate positive correlation. For example, the correlation between 'Weight' (N application rates) and 'SPAD' or 'NDVI' falls into this category. Deep purple (0.4 - 0.5) indicates a weak to moderate correlations. For instance, the correlation between 'Weight' and 'N content' or 'N content' and 'yield' falls within this range. By observing the colors in the heatmap, one can identify which variables are strongly correlated, moderately correlated, weakly correlated, or have no apparent correlation. This information helps in understanding the relationships between different features in the dataset, which is crucial for further analysis and modeling, especially in predictive modeling tasks. Several other researchers have reported that N-content in crops could be monitored using non-destructive approaches like GreenSeeker (NDVI), SPAD meter, remote sensing, UAV (unmanned vehicle) based hyperspectral camara and also by using machine learning tools [12] [13] [14].

Fig. 6. Heat map showing multi-relationship of studied parameters

IV. CONCLUSION

The study revealed a positive and significant correlation between leaf N and optical sensor indices (NDVI) and SPAD values. Thus these sensors can replace the use of the laboratory wet chemistry approach for plant N estimations which is a costly and time-consuming method. The sensor indices and grain yields at large increased with N- application and peaked at 150 kg N /ha. Thus better growth and yields of wheat can be achieved with the application of 150 kg N/ha. The machine learning tool- based analyses of data also revealed a strong correlation between certain features suggestive of multi-co-linearity, which could be considered in further analysis for the predictive model. However, ll further in-depth studies using sensors and machine learning tools are suggested for refining the inferences regarding the prediction of wheat leaf N and making N application recommendations.

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