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Research Article

Estimation of Sensor-based site specific variable rate fertilizer application for maize (*Zea mays L.*) crop

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Abstract
Optical spectrometry sensors in crops offer a remarkable technological breakthrough in the field of variable-rate nitrogen fertilization. A field study was conducted during rainy (*kharif*) season of 2021 at the research farm of the Agricultural Engineering College and Research Institute Tamil Nadu Agricultural University Coimbatore to estimate maize crop nitrogen (N), Normalized Difference Vegetation Index (NDVI) value and chlorophyll content in hybrid maize COH (M) 8. Fertilizers were administered to the plots following the recommendations (250:75:75 kg NPK ha^{-1}) given under Soil Test Crop Response, with a goal yield of 9t ha^{-1} predicted based on the initial soil available N, P, and K values. The experimental findings revealed a significant impact of nitrogen rate ($P<0.001$) on the percentage of nitrogen content in the leaves (% N leaf content). Additionally, there was a decrease in maize leaf chlorophyll content index over time, with ranges of 32.96 to 50.57, 28.78 to 41.78, 24.81 to 35.86, 22.12 to 28.54, and 14.34 to 20.56. On the contrary, the NDVI experienced an increase throughout the season, with ranges of 0.32 to 0.49, 0.30 to 0.55, 0.28 to 0.66, 0.46 to 0.88, and 0.56 to 0.84. The study will help foster sustainability within modern intensive farming practices by emphasizing the importance of reducing environmental pollution caused by applying Sensor-based site-specific nitrogen fertilizer for maize crop.

Keywords: Chlorophyll content Index, Optical sensors, NDVI Value, Nitrogen fertilization

INTRODUCTION

Maize is a globally renowned cereal with exceptional genetic yield potential, surpassing other cereals in productivity. It ranks among the world's most important cereal crops, alongside wheat and rice, in terms of acreage and production. Among the maize-growing countries, India ranks 4th in area and 7th in production, representing approximately 4% of the world's maize area and 2% of total production (Food and Agriculture Organization, 2021). In 2020-21, India produced 31.51 million tonnes of maize across 9.9 million hectares, and in the subsequent *kharif* season of 2021-22, production reached 21.24 million tonnes with a cultivation area of 8.15 million hectares according to data from the Department of Agriculture & Farmers Welfare, Government of India, 2022 (https://agricoop.nic.in)

Fertilizer plays a vital role as a necessary input in crop production to grow, develop, and attain the highest potential yield. Nitrogen (N) stands as one of the most crucial nutrients for plants, serving as a fundamental component in various biological compounds that play vital roles in photosynthesis and agricultural productivity. The availability of nitrogen significantly impacts the growth of maize plants and the ultimate yield of grains. (Sandhu *et al.,* 2021). N fertilization strategy is a major consideration in field management and for cereal crop production, it does not follow any kind of generalized methodology that guarantees maximum nitrogen use efficiency (NUE). To optimize N usage, growers need to understand alternative sources of N for crops besides fertilizer and minimize N loss. Assessing tissue N status and prescribing a N dressing plan based on nitrogen content and build-up in crop plants is essential for supplying N at the right time and in the right quantity. During the initial growth stages up to V4 Vegetative stage (four leaves with collars visible) maize absorbs approximately 10-20% of its total nitrogen requirements. However, in the subsequent six weeks from V4 to VT (Tasseling stage), nitrogen accumulation significantly increases, accounting for about 60-70% of the total nitrogen uptake (Bojtor *et al.,* 2021). The effectiveness of applied nitrogen fertiliser varies on the appropriate quantity, timing, and application technique, the crops, and various genotypes of the same crops.Under natural conditions, nitrogen (N) fertilizer is susceptible to various losses, including denitrification, volatilization, leaching, surface run-off, and fixation with clay colloids. The conventional approach of uniformly applying fertilizer poses challenges, particularly in the case of nitrogen (N) fertilization, as it can result in uneven distribution and undesirable outcomes across different areas of the field. This can lead to both under-fertilization and over-fertilization in specific regions (Mirzakhaninafchi *et al.,* 2022).

Insufficient N fertilization can reduce yield in standing crops like rice, maize, and wheat. Conversely, excessive N application can lead to lodging during harvesting and have detrimental environmental impacts (Xu J *et al.,* 2012 and Shi *et al.,* 2022). Over application of N in cereal crops further lowers N fertilizer use efficiency. Globally, it has been observed that crops do not utilise a significant portion, ranging from 50% to 75% of the applied nitrogen (N) fertilizer. In the case of maize (Zea mays L.), the recovery of applied N seldom surpasses 50% (Modolo *et al.,* 2018).

Nitrogen deficiencies levels often lead to reduced leaf area, photosynthesis, and biomass in rice, resulting in diminished crop production. On the other hand, an excessive supply of nitrogen can result in negative environmental consequences, as well as potential economic and health issues, which must be taken into account (Wang *et al.*, 2020). For instance, when additional nitrogen is applied, the soil becomes susceptible to leaching, which can lead to the contamination of groundwater and air (Liang *et al.*, 2021 ; Deng *et al.*, 2021). Precision agriculture, utilizing spatial data on plant status and soil characteristics, can be defined as the amalgamation of techniques and equipment to predict the specific requirements of crops and apply them at the precise time and location. Employing this approach improves fertilizer utilization efficacy and crop quality, improving productivity (Jiang *et al.,* 2021).

The presence of site-specific variable-rate fertilizer application equipment is crucial to address the distinct needs of each location and provide nitrogen (N) fertilizer accordingly. Given that N deficiency currently contributes to approximately 77% of the global farm-output gap, ensuring accurate N application is paramount in enhancing crop productivity (Barbieri *et al.,*2021*).* Site-specific nutrient management can improve crop production, profitability, and nutrient usage efficiencies (NUE) across diverse ecological contexts. Hence, there is a need to establish recommendation tools that enable precise and efficient management of nitrogen (N) fertilizers, while mitigating the potential negative impacts. Various low-cost technological solutions have recently emerged, facilitating real-time sensing of crop N status.

Various gadgets like the leaf colour chart (LCC), GreenSeeker, SPAD meter, and CCM-200 enhance nitrogen use efficiency in agriculture. They indirectly assess crop nitrogen status, aiding in determining optimal timing and quantity of in-season nitrogen fertilizer for maize cultivation (Singh *et al.,* 2021*)*. Burns *et al.* (2022) investigated Canopy reflectance sensors that are emerging for accurate nitrogen fertilizer estimation, using vegetation indices like NDVI, GNDVI, and chlorophyll content index to detect nitrogen deficiency and predict maize grain yield. NDVI is one of the well-known vegetation metrics for reflecting specific canopy conditions.

The utilization of optical sensors, specifically GreenSeeker, in the Site-Specific Nutrient Management (SSNM) approach has resulted in a reduction of 20-30 kg of nitrogen (N) per hectare without compromising grain yield in conservation agriculture (CA)-based cereal systems (https://www.pau.edu/content/pf/pp_rabi.pdf). Ali *et al.* (2017) on maize demonstrated that in-season measurements of NDVI reliably predict total nitrogen uptake at maturity. The NDVI principle relies on the absorption of red-light by chlorophyll in plants, with near-infrared light being reflected by the leaves. GreenSeeker technology has versatile applications in detecting plant health variations that may not be visible to the naked eye. It provides an average value of the readings displayed on its screen, indicating NDVI readings ranging from 0.00 to 0.99. Interestingly, Preza Fontes *et al.* (2019) found that NDVI had a stronger correlation with maize biomass and nitrogen uptake than RENDVI. However, RENDVI (Red-edge NDVI) demonstrated a stronger association with maize grain yield.

To ensure precise fertilizer application according to the crop's needs, the crop status was evaluated using the normalized difference vegetation index (NDVI) calculated by the Greenseeker sensor. A real-time algorithm was employed to convert the NDVI values into recommended nitrogen (N) levels. SPAD values have the potential to detect N deficiencies in crops and enhance N fertilization management, as leaf chlorophyll and crop N content are closely correlated. The present study aimed to amalgamate some of the concepts for N management in maize production for real-time fertiliser application using gadgets like chlorophyll meters and optical sensors.

MATERIALS AND METHODS

Experimental site description and field trial management

Field experiment to study maize's spectral characteristics and crop growth parameters under variable nitrogen application rates was conducted at the Research Farm of the(Agricultural Engineering College and Research Institute Tamil Nadu Agricultural Univesity) Coimbatore. The soil was red sandy loam in texture and the pH and electrical conductivity of the soil was normal, with values of 7.1 and 0.14 dS $m^{-1,}$ respectively. Subsamples of soil were randomly obtained using a soil auger from six locations on the site at depths ranging from 0-0.15 cm to determine initial soil parameters.The total N of the composite samples was determined using the Kjeldahl digestion method (Okalebo *et al.,* 2002). The soil of the selected site was low in available nitrogen (235.2 kg ha^{-1}), medium in available phosphorus (14.83 kg ha^{-1}) and potassium (240 kg ha^{-1}). Fertilizers were applied in the plots as per the recommendations (250:75:75 kg NPK $ha\text{-}^{1}$) given under Soil Test Crop Response (Crop Production Guide Agriculture 2020, Directorate of Agriculture TNAU, Coimbatore) estimated based on the initial soil available N, P, and K values with a target yield 9 t ha^{-1}. All the analyses were conducted at the Soil Science & Agricultural Chemistry laboratory in TNAU, Coimbatore (TNAU, Soil Test Crop Response Correlation, 2018) The characteristics of basic soil fertility analyses are presented in Table 1.

Experimental design and treatments

The experiment was conducted with four treatments (T_1 =0, T_2 = 75, T_3 = 100, T_4 = 125 kg $ha\text{-}^{1}$ N) and three replications in a Randomized Block Design with the maize variety hybrid COH (M) 8. Maize was planted in 5 meter long and 4.5 meter wide plots and spacing was kept 25 cm for plant to plant and 60 cm from row to row. Therefore, the plot size was 22.5 meter square for each treatment. All other agronomic practices were followed as per the package of practices recommended by TNAU, Coimbatore for maize crop. The nitrogen (N) fertilization rates were divided into three applications. Initially, a basal application of 30-40 kg/ha N was applied at the time of sowing. Subsequently, 60-80 kg/ha N was applied as a top dressing in two to three splits. The first split can be administered during the V4-V6 growth stage, followed by additional splits during the V10-V12 (vegetative stage with ten to twelve leaves showing visible collars) and R1-R3 (reproductive) growth stages. The experiment was conducted to estimate normalized difference vegetation index (NDVI) and chlorophyll content in maize crop by using Green Seeker, Chlorophyll Content Meter (CCM-200) and Lab - Spectrophotometer.

Data collection

Spectral properties of maize leaves were measured using Green Seeker, Chlorophyll Content Meter (CCM-200) and Lab- Spectrophotometer. Spectral properties were measured at 10-12 days interval starting from 25 days after sowing (DAS) to initiation of flowering or at different DAS as described.

Data was collected on the chlorophyll content index, total chlorophyll content and NDVI Value. Different samples of the leaves were taken from ten plants of each unit at different stages of the crops (25, 35, 45, 55, 65 and 75 DAS) for total chlorophyll content analysis using the (Hiscox and Israelstam, 1979). The values for chlorophyll a (mg/cm^{-2}), chlorophyll b (mg/cm^{-2}), and total chlorophyll content ($mg/cm\text{-}^{2}$) were derived by performing calculations based on the absorbance measurements at 663 nm and 645 nm, using the equations proposed by (Arnon,1949). These equations are referred to as equations 1, 2, and 3, respectively.

Chlorophyll a = (ml solvent)[(0.0127 ×Absorbance 663) - (0.00269 Absorbance 645)]/Leaf area (cm^2) Eq. 1

Chlorophyll b = (ml solvent) [(0.0229 ×Absorbance 645) - (0.00468 Absorbance 663)]/Leaf area (cm^2) Eq. 2

Total chlorophyll content = (ml solvent)(0.0202 ×Absorbance 645) + (0.00802 Absorbance 663)]/ Leaf area(cm^2) Eq. 3

Chlorophyll content meter (Opti-sciences CCM- 200, USA), which calculates chlorophyll content index (CCI) based on the ratio of transmittance measurement at 653 and 931 nm was used. The chlorophyll content in the leaf was periodically measured at 10-12 day intervals until maturity using a CCM-200 chlorophyll concentration meter. The assessment of chlorophyll content was conducted on the top leaflet of the fourth compound leaves from the apexes of the plants, as described by (Li *et al.,* 2012 and Li *et al.,* 2019).LEDs were utilized to generate beams, ensuring that the sampling process did not cause any harm to the leaf tissues and pigments. The region measured by the sensing head is a circle 0.71 cm^2 in area (9.5 mm diameter). This instrument uses differential transmission at two wavelengths, 653 and 931 nm, (whereas the current production model uses a 655 nm absorbance beam).A total of fifteen measurements using the CCM-200 chlorophyll concentration meter were conducted on four healthy mature leaves of maize. Nitrogen contents can be estimated (Ghasemi *et al.,* 2011) using the following formula based on the CCM readings:

Nitrogen=0.0309CCI+1.221 Eq. 4

These measurements were taken from the middle portion of non-fruiting branches. Subsequently, the nitrogen content of these leaves was analyzed using the Kejeldal method. The distilled sample was titrated with a standard solution of 0.02 N H_2SO_4 until the end point and the N concentration of the sample was calculated using the equation: (Jaroonchon *et al.,* 2010)

Total N concentration in a sample (%) = (Vs-Vb) × N × 0 .014 × Vd × 100 / W × Va Eq. 5

Where

Vs = amount of a standard H_2SO_4 (mL) used for titration to reach end point,

Vb = amount of a standard H_2SO_4 (mL) used for titration of the blank,

N = H_2SO_4 concentration (0.02 N),

Vd = amount of digested sample solution (mL),

W = sample weight (g) and

Va = amount of a sample solution for the analysis (10 mL) At the same time ten readings also were taken for chlorophyll analysis. The NDVI was also taken at 10-12 days intervals till maturity using the GreenSeeker Sensor. Nitrogen doses using GreenSeeker were calculated as per the procedure developed by Raun *et al.* *(*2005) and Crain *et al.* (2012) and separated into several discrete components: The NDVI measurements made by GreenSeeker are based on reflectance by the plant in infra-red (IR) and near infra-red (NIR) wavebands as following formula:

NDVI = (NIR ref – RED ref) / (NIR ref + RED ref) Eq. 6

In this equation, NIRref and REDref represent the reflectance values in the near infrared and red bands, respectively. NDVI serves as a measure of total biomass and leaf greenness, and it is commonly used for mid-season predictions of final grain yield. The algorithm, derived from Cornell University's Nutrient Management Spear Program, offers reliable guidance for optimal N management. By relying on the correlation between NDVI and nitrogen uptake instead of crop yield, it delivers superior results in determining appropriate nitrogen fertilizer application rates.

Fig.5 presents the data related to NDVI values obtained at 25 to 75 days after sowing (DAS). The NDVI values at different DAS were influenced by the initial fixed nitrogen doses applied at planting and tasseling stages (25 DAS). Lowest NDVI values were recorded in T1 as it received comparatively lower N of 0 kg ha-^{1}. At 50 DAS, the treatment following the recommended N schedule (100 kg/ha) recorded the highest NDVI values, followed by treatments where an initial dose of 75 kg/ha (T_2, T_3, and T_4) was applied as given in Table 2. In-season estimate of response index (RI_{NDVI}) helps to predict the extent of response of present crop to added fertilizer N in that season and for that field.

RESULTS AND DISCUSSION

Total chlorophyll content, chlorophyll content index and NDVI values

The statistical analysis revealed a linear correlation between CCM readings and leaf chlorophyll content. An

Table 1. Physical and chemical properties of soil in the (AEC&RI, TNAU Coimbatore) field

S.No.	Particulars	Values	Method followed
1	Sand (%)	72.3	Bouyoucos Hydrometer method (Piper, 1966)
2	Silt (%)	9.6	
3	Clay (%)	18.2	
4	Texture	Red sandy loam	
5	Bulk density (g/cm^3)	1.51	Core sampler (Piper, 2002)
6	pH (1:2.5 Soil : water)	7.3	Glass Electrode pH meter) (Jackson,1967)
7	EC(1:2.5 Soil : water) (dSm^{-1})	0.34	Conductivity bridge(Jackson,1967)
8	Soil organic carbon (%)	0.40 - 0.46	Wet oxidation (Walkley and Black (1973)
9	Available Nitrogen (kg ha^{-1})	235.2	Alkaline permanganate method (Subbiah and Asija, 1956)
10	Available Phosphorus P2O5 (kg ha^{-1})	14.83	Bray's extractant Jackson (1973)
11	Available Potassium K_2O (kg ha^{-1})	240	Jackson (1973)

Table 2. Fertilizer N (kg ha^{-1}) application time and doses received by the maize crop in different treatments

Fertilizer N	Dose kg ha^{-1}			Total kg ha^{-1}
	Basal (25%)	At 1st irrigation (50%) (30DAS)	At 2nd irrigation (25%) (45DAS)	
T_1 (0 kg ha-^{1} N)	0	0	0	0
T_2 (75 kg ha-^{1} N)	46.75	93.5	46.75	187
T_3 (100 kg ha-^{1} N)	62.5	125	62.5	250
T_4 (125 kg ha-^{1} N)	78.12	156.25	78.12	312.5

analysis of variance (ANOVA) showed the variations in CM-200 values, percentage of total leaf nitrogen content, and NDVI values. The results showed that nitrogen fertilizer had a substantial influence on the percentage of nitrogen content in the leaves ($P < 0.001$) from V6 to VT (Tasseling) stage in maize. Each level of nitrogen fertilizer significantly increased leaf nitrogen content. Regression equations were derived to establish a relationship between the nitrogen (N) leaf content percentage and the CCM (Crop Condition Monitoring) value at various crop growth stages. The equation obtained was $Y = 0.0343x + 1.0027$.

Table 3 shows the results for chlorophyll a (mg/cm-²), chlorophyll b (mg/cm-²), total chlorophyll content (mg/cm-²) of the maize leaves. The range of chlorophyll a was observed to be between 0.09 and 0.80 mg/ cm-², with a mean value of 0.26 mg/ cm-². Chlorophyll b ranged from 0.22 to 1.06 mg/ cm-², with a mean of 0.68 mg/ cm-².The total extractable chlorophyll content ranged from 0.40 to 1.31 mg/ cm-², with an average of 0.98 mg/ cm-².Data analysis revealed a linear correlation between chlorophyll a, chlorophyll b, and total chlorophyll content obtained from CCM readings, with R^2 values of 0.53, 0.81, and 0.90, respectively. These findings suggest that the CCM-200 can potentially estimate chlorophyll content in maize leaves.

The CCM readings ranged from 14.34 to 51, with a mean value of 35.19. The nitrogen percentage in the leaves varied from 1.66 to 2.78%, with an average of 1.99%. The results of nitrogen analysis in the leaves were correlated with the chlorophyll meter readings, as depicted in Fig.1. Each chlorophyll meter reading represents the average of twelve measurements taken on four leaves. Correlation analysis demonstrated a linear relationship between CCM readings and nitrogen content in the leaves, with an R^2 value of 0.75.

In the T_1 treatment, the lowest percentage of nitrogen (% N) leaf content was recorded, while the highest was observed in the T3 treatment ($P<0.001$), as shown in Fig. 2. Generally, there was an increasing trend in % N leaf content with higher levels of nitrogen application. The chlorophyll content also continuously increased with increasing nitrogen levels up to 125 kg N/ha. However, a decrease in nitrogen percentage was observed when the CCM readings were below 14. It was found that the CCM-200 measurements had positive correlations with both the total chlorophyll content and nitrogen content in maize leaves. Consequently, it is logical to anticipate that the nitrogen content in leaves could serve as a reliable indicator of the nitrogen content in grains during maturity. Furthermore, the nitrogen content in Maize leaves could be a valuable indicator of the overall nitrogen status of the entire plant. CCI and NDVI values increased with N levels. The increase in CCI and NDVI values with higher N levels can be attributed to the role of nitrogen in promoting chlorophyll

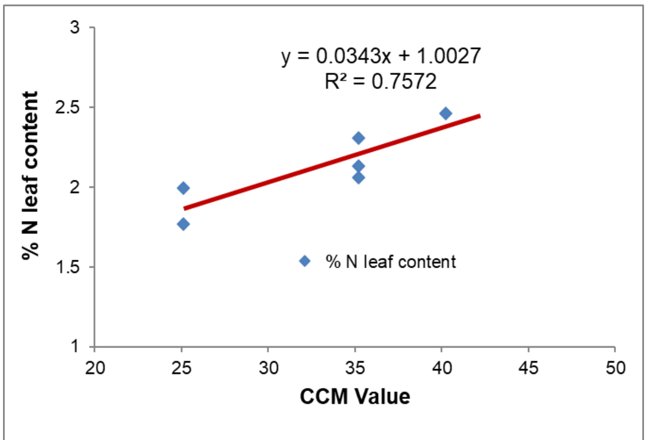

Fig. 1. *Linear correlation between % N leaf content and chlorophyll meter readings in maize leaves*

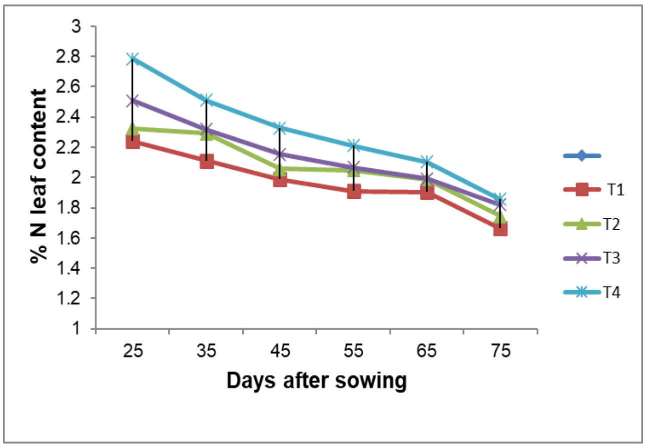

Fig. 2. *Variation of % N leaf content values with days after sowing (DAS)*

synthesis, which enhances photosynthetic activity and overall plant vigor However, at the late stages of the crop, the means of % N leaf content of the different N treatments did not differ significantly. Singh and Singh (2022) found that during spring maize's early vegetative growth stages (V6 to V9), SPAD meter readings increased due to sufficient N supply from native soil sources and basal N doses. However, at V12 growth stages, the No-N control and low fertilizer N treatment showed declining SPAD meter (chlorophyll content) readings due to reduced chlorophyll synthesis caused by inadequate N supply and increased N dilution with higher plant biomass. At the tasselling stage, all treatments, including the No-N control, exhibited higher SPAD meter (chlorophyll content) readings, and attributed to the shift in the index leaf from the topmost fully expanded leaf to the ear leaf.

Based on the present study findings, the N (%) of maize leaf and leaf chlorophyll content decreased as the season continued, whereas the NDVI values increased as the season continued (Figs. 2-5). After the vegetative growth stage, leaf chlorophyll content decreased generally as the season continues. Hence, when there is an increase in leaf area and higher levels of green plant biomass, it can increase in leaf area. Higher levels of green plant biomass lead to elevated reflectance and subsequently higher NDVI values. As these factors are closely linked to the nitrogen content

Table 3. Chlorophyll a, Chlorophyll b , total chlorophyll content readings in leaves of maize crop on different days after sowing (DAS) with three replications

Treatment	Chlorophyll a (mg/cm^{-2} of fresh weight)	Chlorophyll b (mg/cm^{-2} of fresh weight)	Total chlorophyll Content (mg/cm^{-2} of fresh weight)
(25 DAS)			
T_1	0.09	0.22	0.40
T_2	0.16	0.28	0.61
T_3	0.21	0.35	0.72
T_4	0.19	0.35	0.77
(35 DAS)			
T_1	0.11	0.27	0.44
T_2	0.23	0.37	0.60
T_3	0.30	0.45	0.79
T_4	0.38	0.34	0.82
(45 DAS)			
T_1	0.30	0.29	0.69
T_2	0.38	0.92	1.08
T_3	0.39	0.95	1.25
T_4	0.42	1	1.31
(55 DAS)			
T_1	0.29	0.33	0.68
T_2	0.23	0.96	1.25
T_3	0.76	1.06	1.30
T_4	0.80	0.96	1.28
(65 DAS)			
T_1	0.25	0.35	0.72
T_2	0.47	0.81	0.95
T_3	0.59	0.84	1.08
T_4	0.63	0.87	1.10
(75 DAS)			
T_1	0.19	0.31	0.64
T_2	0.30	0.87	0.75
T_3	0.38	0.91	0.90
T_4	0.42	0.83	0.94

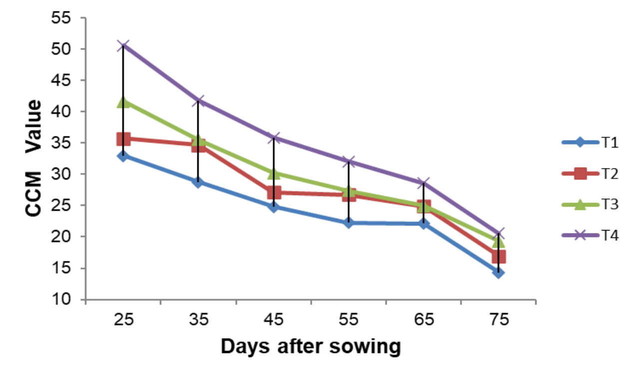

Fig. 3. *Variation of CCM-100 with days after sowing (DAS)*

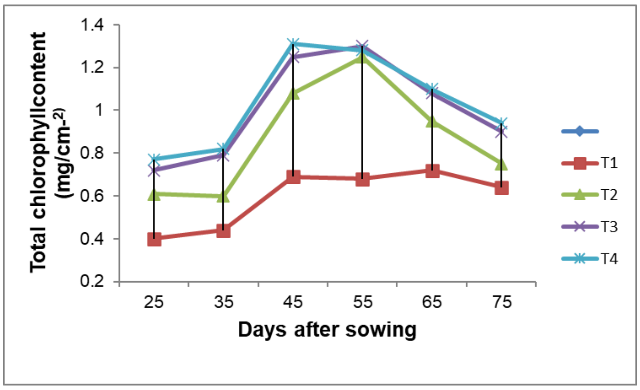

Fig. 4. *Variation of Total chlorophyll Content with days after sowing (DAS)*

of the plant, higher NDVI values indicate a higher nitrogen content. These characteristics make NDVI a valuable tool for assessing the relative nitrogen status of plants by comparing the NDVI values of adequately-nourished plants to those with nitrogen deficiencies.

Correlation values between Leaf N, CM100 and NDVI values

Significant positive correlation coefficients were observed between the percentage of nitrogen %N leaf content and both CM-100 (r = 0.87***) and NDVI values (r = 0.89***) during the vegetative stage of the crop. At the tasseling initiation stage, a significant Pearson's correlation was found between % N leaf content and CM-200 (r=0.75***), but no significant correlation was observed between % N leaf content and NDVI values (r=-0.94). Therefore, CM-200 can be utilized for in-season nitrogen status determination during the crop's vegetative and tasseling tiller initiation stages. On the other hand, GreenSeeker is suitable for nitrogen management during the growing season's vegetative and reproductive stages. NDVI measurement in this study reached saturation at the vegetative stage of the crop. This finding indicates that CCM technology outperformed NDVI technology in its ability to detect nitrogen deficiency at an early stage. Edalat *et al.* (2019) discovered that NDVI values could effectively detect nitrogen deficiency in the early stages of maize plant growth, as they were notably higher in all nitrogen rate treatments (80, 160, and 320 kg N ha^{-1}) compared to the control groups without fertilizer. Dhakal *et al.* (2021) found that nitrogen uptake peaks during mid-vegetative growth, but limited soil supply during anthesis intensifies N remobilization to maize grains, due to the higher N demand for grain development compared to vegetative tissues.

The present study assessed the efficacy of GreenSeeker technology in determining the need for a supplementary nitrogen-sidedress application to enhance yield at the V12 (Vegetative stage with twelfth leaf collar). Additionally, the performance of green-based vegetation indices in evaluating maize vigor was investigated, considering the challenges of saturation typically associated with NDVI measurements during the later stages of vegetation growth. Based on present study findings, it is evident that both the GreenSeeker Sensor and CM-200 are not suitable for late-stage nitrogen management in maize. However, NDVI values obtained from the GreenSeeker sensor can be utilized for predicting maize yield at various crop stages, except for the reproductive (kernel development) stage. Nonetheless, when it comes to yield prediction, using these sensors during the vegetative stage may yield more reliable results than the crop's later growth stages. Earlier research on potato crops by Wilkinson *et al.* (2019) demonstrated a highly significant correlation coefficient between tuber yield and leaf chlorophyll content values measured using SPAD.

Regression values between NDVI value and N fertilization

The following regression equations and determination coefficients were obtained between NDVI value at different DAS and N-fertilization. DAS25: $y = 0.0006x + 0.3403$, $R^2 = 0.4293$, DAS35: $y = 0.0019x + 0.2998$, $R^2 = 0.8986$, DAS 45: $y = 0.0032x + 0.2856$, $R^2 = 0.996$, DAS 55: $y = 0.0039x + 0.2497$, $R^2 = 0.8886$, DAS 65: $y = 0.0034x + 0.4661$, $R^2 = 0.9838$,DAS 75: $y = 0.0023x + 0.5588$,$R^2 = 0.9996$, (all F-values were significant at 5%) (Fig.5-7).The obtained regression slopes between NDVI values and N fertilization were high during the tasselling, kernel development, and silking stages of the crop. This suggests that maintaining an optimal NDVI value during tasseling initiation and kernel development stages is crucial for achieving higher crop yields. It emphasizes the importance of adequate soil fertility management during these stages to maintain the percentage of nitrogen (% N) leaf content, NDVI, or leaf chlorophyll content at optimum levels.

To ensure efficient utilization of these optical sensors, further research is recommended in various maize

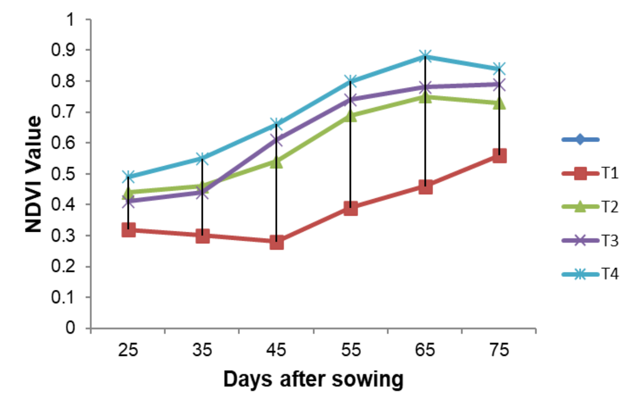

Fig. 5. *Variation of NDVI value with days after sowing (DAS)*

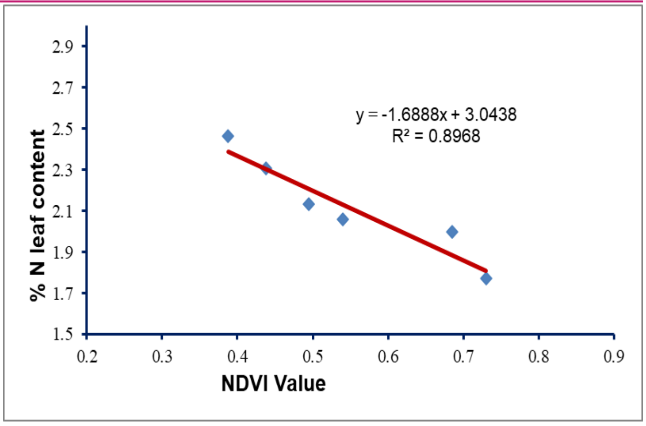

Fig. 6. *Linear correlation between % N leaf content and NDVI value.*

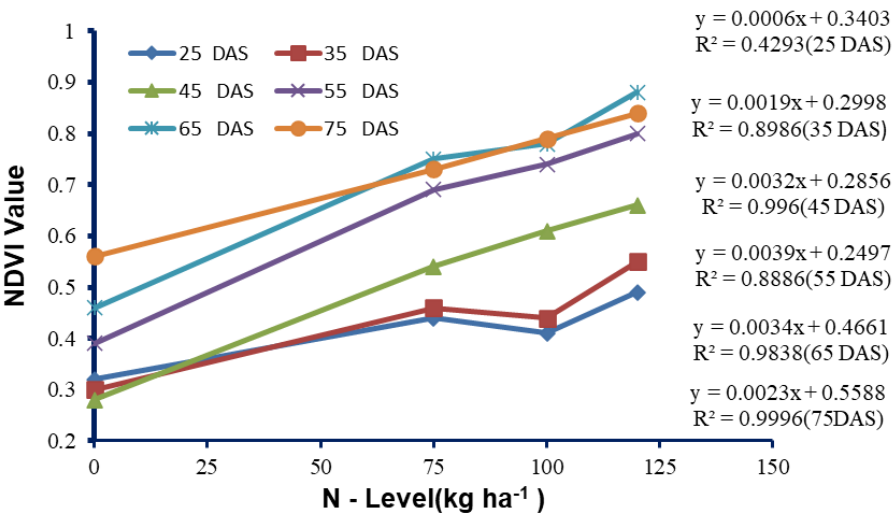

Fig. 7. *Regression between NDVI Value and N -Level at different growth stages of maize crop*

cropping regions, using different maize varieties, to determine the threshold values of CM-200 and GreenSeeker at different crop growth stages. This will help in refining the understanding of optimal sensor values for accurate nitrogen management in maize cultivation. But Singh *et al*. (2022) found that applying fertilizer N management using LCC 5 and SPAD 50 from the six-leaf stage until just before the silking stage significantly improved agronomic efficiency in maize cultivation. No response to fertilizer N application was observed at the silking stage. Naser *et al.* (2020) found a strong correlation between grain yield and NDVI at three critical growth stages (early growing season, anthesis, and mid-grain filling) in dryland conditions, showcasing NDVI potential as a valuable tool for differentiating and identifying superior wheat genotypes.

Conclusion

The present study concluded that N fertilization should be proportional to the crop need and applied at the right time to achieve an optimum yield and high quality of maize crop.This innovation can potentially enhance nutrient use efficiency (NUE) while reducing the negative environmental effects associated with traditional fertilization methods. Therefore, adopting a split application approach for mineral nitrogen (N) fertilizer throughout the maize growing season is the appropriate and suitable method to match the crop's N requirement and supply. This study revealed that the CCM-200 chlorophyll meter could be effectively used for in-season N management at the vegetative and kernel initiation stages, while GreenSeeker sensors are limited to use only at the vegetative stage due to early saturation.For yield prediction, the CM-200 chlorophyll meter can be utilized throughout the entire growing season of the maize crop. The GreenSeeker sensor can also be employed for kernel yield prediction at all stages of maize growth except the tasseling initiation stage. To achieve efficient yield and nitrogen recommendations, the CM-200 chlorophyll meter is recommended, although the GreenSeeker sensor can also be used during the early stages of the crop. Furthermore, the study suggests the development of a manually operated optical sensor for late-stage N management in maize. Additionally, it recommends further investigations in different maize-growing regions of the southern region of Tamil Nadu state to establish different thresholds at various stages of the crop.

Conflict of interest

The authors declare that they have no conflict of interest.

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