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A novel approach for increasing productivity under precision nitrogen management in maize (*Zea mays* L.) through crop sensors

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Abstract
Global maize production reached 1075 million tons in 2016, according to the FAO database. While maize is considered as staple food for many populations across the globe, increasing the productivity using crop sensors like SPAD chlorophyll meter and GreenSeeker meter in maize could be a effective tool to achieve sustainable developmental goal- end hunger and secure food security. The current approaches to detect soil and plant N levels are soil-testing, visual diagnosis and foliar analysis. However, these conventional approaches are time consuming, expensive; require considerable effort for soil collection or plant sampling, processing and results are not immediately available. Therefore, to provide appropriate recommendations of spatial N applications, it is necessary to use several tools simultaneously, such as crop and soil sensors, to achieve reliable measurements of N availability from soil and crops need. The result showed in pooled data of 2016 and 2017, increased growth parameters (*viz*., plant height, number of green leaves, leaf area, dry matter production and SPAD chlorophyll readings) and yield parameters (*viz*., number of cobs per plant, cob length and girth, kernels per row, kernels per cob, grain yield and stover yield) recorded in STCR based NPK management for target of 11 t ha^{-1}. However, the nitrogen use efficiency was registered in highest in N management through SPAD-40, N_{25}, but recovery use efficiency, agronomic efficiency and physiological efficiency were higher under GreenSeeker based nitrogen management (NDVI values).

Keywords: Maize, productivity, Nitrogen, NUE and crop sensors

Introduction
Maize (*Zea mays* L.) is one of the important cereal crop next to wheat and rice in the world. It is called as “Queen of Cereals” because of its productive potential compared to any other cereal crop and “King of Fodder” due to its great importance in animal diet. Globally, it is grown over an area of 185.90 m. ha with an annual production of 1,075.49 m. t. with a productivity of 5790 kg ha^{-1} (Anon., 2016) [3]. In India, it stands third in area and production after rice and wheat. Currently it is cultivated in an area of 9.89 m. ha with a production of 25.90 m. t. and it contributes to nearly 9 per cent of the national food basket (Dass *et al*., 2012) [10]. However, the productivity in India is much lower (2620 kg ha^{-1}) than world average (Anon., 2016) [3]. The states that contributes, more than 80 per cent of total maize production are Andhra Pradesh (20.9%), Karnataka (16.5%), Rajasthan (9.9%), Madhya Pradesh (5.7%) and Himachal Pradesh (4.4%). In India, about 35 per cent of the maize produced is used for human consumption, 25 per cent each in poultry and cattle feed and 15 per cent in food processing industries for preparation of corn flakes, popcorn, starch, dextrose, corn syrup and corn oil *etc*. Karnataka is not only a major maize producing state but also a major seed producing state in the country. In the state, maize is grown over an area of 1.18 m. ha with a production and productivity of 3.28 m. t. and 2773 kg ha^{-1}, respectively (Anon., 2015) [2]. During the last ten years, the area under maize in Karnataka has increased by 41 per cent.
Nutrient management is one of the major constituent in maize cultivation. Among those, nitrogen (N) is the most widely used fertilizer nutrient for maize and its consumption has increased substantially in the past decades (FAOSTAT, 2009). Nitrogen management is important for maize production, as it helps in achieving desired yield and protein content. Nitrogen is often considered as the most limiting nutrient for crop production in many regions of the world (Giller, 2004), that’s why N fertilizer is one of the main inputs for cereals production systems. Globally, the nitrogen use efficiency (NUE) for cereal production including maize is approximately 30 - 40 per cent (Raun and Johnson, 1999). NUE may be affected by crop species, soil type, temperature, application rate of N fertilizer, soil moisture condition and crop rotation (Halvorson *et al.,* 2001). The main reason for low N use efficiency is an inefficient splitting of N doses coupled with N applications in excess of crop requirements.

Blanket application of nitrogen (N) fertilizer lead to low nitrogen use efficiency due to variability present within the field in soil N supply and seasonal variability in yield in large irrigated maize tracts because these blanket recommendations are developed for large areas having similar kind of land forms and climate without considering the nitrogen release from organic manures, crop residues and irrigation water. Sometimes the farmers apply nitrogen fertilizers more than the recommended dose to ensure higher yields but over application of nitrogenous fertilizers leads to several other problems resulting in low nitrogen use efficiency. Excessive plant-available N produces maize plants that are susceptible to lodging, insect pest and disease resulting in decreased yields and increased input costs. The partial factor productivity per unit of applied fertilizer N has decreased to very low values during the past decades (Doberman *et al*., 2002) which imply that for producing per unit of maize grain we have to apply more N fertilizer than before.

Efficient nitrogen (N) fertilization is crucial for economic maize production. The absorption of N by crops is variable among and between seasons, as well as between locations in the same field, even when the N supplies are high. The N supply from soil to crop varies spatially. Consequently, the demand for N by the crop also varies. As a result, the crop's nutritional status is a good indicator of the necessary N rate application. Nitrogen fertilizer rate and timing are the major tools available after planting to manipulate maize to produce higher yields per unit area. As fertilizer N has generally been managed following blanket recommendations consisting of two or three split applications of preset rates of the total amount of N, improvement in N use efficiency could not be achieved beyond a limit. Feeding crop N needs is the most appropriate fertilizer N management strategy to further improve N use efficiency. Since plant growth reflects the total N supply from all sources, plant N status at any given time should be a better indicator of the N availability.

To improve the nitrogen use efficiencies various practices are followed such as use of nitrification inhibitor controlled release nitrogenous fertilizer, deep placement of nitrogenous fertilizers *etc*., There are also different types of gadgets available for improving nitrogen use efficiency such as leaf colour chart (LCC), GreenSeeker, SPAD meter which can indirectly estimate crop N status of the growing crops and help define time and quantity of in-season fertilizer N top dressings wheat. Supplemental fertilizer N applications are thus synchronized with the N needs of crop.

The current approaches to detect soil and plant N levels are soil-testing, visual diagnosis and foliar analysis. However, these conventional approaches are time consuming, expensive; require considerable effort for soil collection or plant sampling, processing and results are not immediately available. Therefore, to provide appropriate recommendations of spatial N applications, it is necessary to use several tools simultaneously, such as crop and soil sensors, to achieve reliable measurements of N availability from soil and crops need. The evaluation of nitrogen use efficiency (NUE) in agriculture is an important way to evaluate the density of N applied and its role in yield. Because crop responses to N application depend on the organic matter in the soil, strategies of N management in cereal crops that include reliable predictions of the response index in each season could increase NUE. In this scenario, sensors are becoming more prevalent in agricultural lands. Using variable rate equipment or application, it is possible to detect variability in crops and make rapid decisions in the field. Some sensors allow real time changes in agricultural practices by detecting variability and responding to that variability.

Sensors utilize the optical characteristics of plants and their associated vigor and health properties. Recent advances in precision agriculture technology have led to the development of ground-based active remote sensors (or crop canopy sensors) that calculate NDVI readings. Crop canopy sensors are relatively small in size and contain an integrated light source. They operate by directing visible light (VIS) (400–700 nm) as well as near infrared (NIR) (700–1300 nm) light at the plant canopy of interest. The amount of VIS and NIR light that is reflected by the plant canopy is measured and an NDVI value is calculated using suitable equations.

GreenSeeker is an integrated optical sensing and application system that measures crop nitrogen status and variably applies the crop's nitrogen requirements. Yield potential for a crop is identified using a vegetative index known as NDVI (normalized difference vegetative index) and an environmental factor. Nitrogen (N) is then recommended based on yield potential and the responsiveness of the crop to additional nitrogen. The SPAD meter or handheld chlorophyll meter provides a non-destructive method to access the nutrient status of the crop. It measures the quantity of light transmitted through the leaf. Increasing chlorophyll content results in decreasing light transmittance. Chlorophyll readings from nutrient deficient plots are compared to readings from reference plants where nutrients are non-limiting. The main advantage of using a chlorophyll meter is its ability to detect the nutrient stress before the deficiency symptoms are visible.

Soil test crop response (STCR) approach takes into account the nutrient requirements of a crop to produce unit yield, likely contribution from soil and from the fertilizer to know fertilizer to be added for a given yield level. Similarly, Site-specific nutrient management (SSNM) approach is one such option which focuses on balanced and crop need based nutrient application (Johnston *et al*., 2009). It provides an opportunity for the timely application of fertilizers at optimal rates to fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources, including soil, crop residues, manures, and irrigation water.

Maize has got wider adoptability under different agro-climatic condition. Precision agriculture technologies are becoming part of many farming operations and can play a key role in sustainable N fertilizer management. Addressing spatial variable fertilizer N requirements with variable rate management strategies can increase profitability.

Efficient nutrient management programmes supply plant nutrients in adequate quantities to sustain maximum crop productivity and profitability while minimizing environmental impacts of nutrient use. Ensuring optimum nutrient availability through effective nutrient management practices requires knowledge of the interactions between the soil, plant and environment.

The purpose of this study is to develop precision nitrogen management technologies and to improve growers' knowledge for effective nitrogen (N) management. The overall goal is to improve the use efficiency of N fertilizer resources and increase crop productivity in a sustained manner. Keeping these above facts, the present study was conducted on "A novel approach for increasing productivity under precision nitrogen management in maize (*Zea mays* L) through crop sensors" at Zonal Agricultural Research Station, UAS, G.K.V.K, Bengaluru during *Kharif* 2016 and 2017 with the following objectives; To study the effect of sensor based precision nitrogen management on productivity and nitrogen use efficiency of maize.

Material and Methods

A field experiment was conducted at ZARS, UAS, Bengaluru during *Kharif* 2016 and 2017. The site is located at 13^0 05' 2'' N latitude and 77^0 34' 02'' E longitudes with an altitude of 930 m above mean sea level. The soil of the experimental site was sandy loam. The initial pH was 5.97 and electrical conductivity was 0.18 dS m^{-1}. The available nitrogen, phosphorus and potassium were 215 to 267 kg ha^{-1}, 37 to 58 kg ha^{-1} and 234 to 265 kg NPK ha^{-1}, respectively. The experiment was laid out in Randomized Complete Block Design (RCBD) with twelve treatments and replicated thrice and the treatments includes T_1: Nitrogen management through SPAD sufficiency index 85-89 per cent, T_2: Nitrogen management through SPAD sufficiency index 90-95 per cent, T_3: Nitrogen management through SPAD sufficiency index 96-100 per cent, T_4: Nitrogen management through SPAD-30, N_{25}, T_5: Nitrogen management through SPAD-35, N_{25}, T_6: Nitrogen management through SPAD-40, N_{25}, T_7: GreenSeeker based nitrogen management, T_8: Nitrogen management through SSNM for target of 11 t ha^{-1}, T_9: STCR based N management for target of 11 t ha^{-1}, T_{10}: STCR based NPK management for target of 11 t ha^{-1}, T_{11}: Recommended dose of N as per package of practices and T_{12}: Absolute control.

The land was brought to fine tilth before sowing by ploughing twice with tractor drawn disc plough and passing cultivator and two harrowing. Drip system including pump, filter units, main line and sub lines were installed. In line laterals of 16 mm size within lines spaced at 45 cm apart with 4 lph capacities were laid out at a distance of 60 cm apart and thereby lateral spacing of 60 cm was fixed. There were 14 maize rows at a distance of 60 cm apart in each treatment extending to 8.4 meter length. Seeds of Hema (NAH-1137) maize hybrids (two seeds per hole) were dibbled at 30 cm interval in the furrows spaced at 60 cm apart. The required fertilizer were calculated and applied as per the treatments. Based on the soil test results in case of SPAD and GreenSeeker based nitrogen management, 25 per cent of the recommended dose of nitrogen was applied as basal along with full dose of P_2O_5 and K_2O. Remaining nitrogen was supplied as per the treatments. In case of SSNM and STCR 50 per cent of the nitrogen was applied as basal and the balance 50 per cent N was applied at 30 and 45 DAS along with recommended P_2O_5 and K_2O were applied at the time of sowing. In case of recommended practices, nitrogen (150 kg ha^{-1}) was applied as per package of practices. Recommended dose of FYM (10 t ha^{-1}) was applied to all the treatments except in case of absolute control and mixed into the soil 15 days prior to sowing. Irrigation was scheduled at weekly interval through drip based on the rainfall, soil and crop appearance during the crop periods. Irrigation was withheld 10 days before the crop attained maturity. Atrazine @ 1000 g *a.i.* ha^{-1} was applied as pre-emergence spray at one day after sowing of maize followed by one hand weeding was attended at 30 days after sowing to control the weeds. During the season earthing up was carried out at 30 days after sowing. Plant population was maintained in all the treatments by thinning out of excess seedlings at 15 DAS and leaving one seedlings per spot. Healthy crop stand was ensured by adopting need based crop protection and recommended packages of practices. Five plants were selected at random and tagged. These plants were used for recording plant height (cm), number of green leaves, leaf area and leaf area index, dry matter production and SPAD chlorophyll readings. Leaf area was measured using leaf area meter and LAI was calculated as ratio of leaf area per plant to area occupied by the plant. Yield attributes like, number of cobs per plant, cob length and girth, number of rows per cob, kernels per row, kernels per cob, test weight, grain yield and straw yield were recorded. The data was statistically analyzed by following standard procedure (Gomez and Gomez, 1984) [12]. Nitrogen use efficiency was calculated by using following formula and expressed in kg kg^{-1} (Crasswell and Godwin, 1984). Different measures of nitrogen use efficiency - recovery efficiency (RE), agronomic efficiency (AE), physiological or internal efficiency (PE) and partial factor productivity (PFP) are calculated by following formula

$$\text{NUE or PFP} = \frac{\text{Grain yield (kg ha}^{-1}\text{)}}{\text{Nitrogen applied (kg ha}^{-1}\text{)}}$$

$$\text{RE (\%)} = \frac{\text{(Total N uptake in N fertilized plot – Total N uptake in no N plot)}}{\text{(Quantity of N fertilizer applied in N fertilized plot)}} \times 100$$

$$\text{AE} = \frac{\text{(Grain yield in N fertilized plot - Grain yield in no N plot)}}{\text{(Quantity of N fertilizer applied in N fertilized plot)}}$$

$$\text{PE} = \frac{\text{(Grain yield in N fertilized plot - Grain yield in no N plot)}}{\text{(Total N uptake in N fertilizer plot – Total N uptake in no N plot)}}$$

Where,
NUE: Nitrogen use efficiency (kg grain kg^{-1} N fertilizer applied)
RE (%): recovery efficiency
AE: Agronomic efficiency (kg grain kg^{-1} N)
PE: Physiological efficiency (kg grain kg^{-1} N uptake)
N uptake was the total N uptake in grain and stover

Results and discussion

Growth parameters

In pooled analysis, growth parameters of maize were significantly influenced by precision nitrogen management though crop sensors (Table 1). Significantly increased plant height (223.86 cm), higher number of leaves $plant^{-1}$ (15.37), leaf area (9836 cm^2 $plant^{-1}$), higher total dry matter production (439.8 g $plant^{-1}$) at harvest was noticed in STCR based NPK management for target of 11 t ha^{-1} and was on par with nitrogen management through SSNM for target of 11 t ha^{-1} (218.82 cm, 15.07, 9597 cm^2 $plant^{-1}$, 429.0 g $plant^{-1}$ and 39.77), GreenSeeker based nitrogen management (215.63 cm, 14.94, 9480 cm^2 $plant^{-1}$, 419.1 g $plant^{-1}$ and 42.28) and nitrogen management through SPAD sufficiency index 96-100 per cent (210.78 cm, 14.59, 9188 cm^2 $plant^{-1}$, 406.8 g $plant^{-1}$ and 40.50). Whereas, significantly shorter plant height (168.73 cm), minimum leaves (9.74), lower leaf area (6295 cm^2 $plant^{-1}$) and lower total dry matter production (287.9 g $plant^{-1}$) were recorded in absolute control.

At 75 DAS, pooled data showed that significantly higher SPAD reading were recorded in GreenSeeker based nitrogen management (42.28) and it was found on par with nitrogen management through SPAD-40, N_{25} (41.46), recommended dose of N as per package of practices (40.90), STCR based NPK management for target of 11 t ha^{-1} (40.76), nitrogen management through SPAD sufficiency index 96-100 per cent (40.50), nitrogen management through SSNM for target of 11 t ha^{-1} (39.77) and nitrogen management through SPAD-35,

N_{25} (38.66). Significantly lower SPAD reading was recorded in absolute control (30.98).

An optimum plant height is claimed to be positively correlated with productivity of plant (Saeed *et al*., 2001). The plant height helps to increase the dry matter production and was increased with successive increase in nutrient levels required to achieve the higher target yields. The increased plant height was due to increased nutrient availability which contributed for prolonged greenness and larger leaf surface. Similar observations were made by Santosh Pagad (2014) [18] and Nagarjun (2015) [16]. Leaf area increased due to synchronization of applied nitrogen between crop demand and supply leads to development of more and more chlorophyll pigments. This in turn increases specific leaf weight and resulted in higher light interception, root development, leaves development and plant height resulted in better dry matter production and distribution in the plant parts especially in cobs and better yield and yield components. These results are in conformity with the findings of El-habbal *et al.* (2010) [11] in wheat. Increased SPAD readings was due to application of nutrients synchronizing with crop demand enhanced growth, leaf turgidity as well as chlorophyll content and improved the efficiencies of fertilizers. The results are in accordance with the findings of Suryavanshi *et al.*, (2008) [22]. The chlorophyll content regulates the photosynthetic efficiency. Precise application of fertilizer N through target yield approach increased the SPAD chlorophyll meter readings and NDVI values. Increase in SPAD chlorophyll meter readings indicates production of appreciable amount of chlorophyll in the leaves. The higher SPAD chlorophyll meter readings with higher target yield levels were due to better schedule of top dressing with nitrogenous fertilizers. These results were also in conformity with Sarnaik (2010) [19].

This increase in total dry matter was due to development of more photosynthetic area in terms of increased leaf area and number of leaves per plant. This is achieved due to synchronization of applied nitrogen between crop demand and supply which resulted in production of chlorophyll pigments since N is the major nutrient in chlorophyll. Similar findings were also reported by Biradar *et al.* (2013) [6].

Yield and yield attributes

Pooled data on yield attributes like, number of cob per plant, cob length and girth, number of rows per cob, kernels per row, kernels per cob, as well as grain yield and stover yield of maize were favorably influenced by precision nitrogen management through crop sensors (Table 2).

The pooled data on grain and stover yield (Table 2) revealed that, significantly higher maize grain yield and stover yield (110.46 q ha^{-1} and 136.83 q ha^{-1}) was recorded with the application of nutrients through STCR based NPK management for target of 11 t ha^{-1} and it was noticed on par with nitrogen management through SSNM for target of 11 t ha^{-1} (108.36 q ha^{-1} and 136.38 q ha^{-1}), GreenSeeker based nitrogen management (107.34 q ha^{-1} and 134.48 q ha^{-1}) and nitrogen management through SPAD sufficiency index 96-100 per cent (107.14 q ha^{-1} and 135.99 q ha^{-1}). Significantly lower grain yield and stover yield (43.09 q ha^{-1} and 68.64 q ha^{-1}) was recorded with absolute control treatment.

Significantly higher grain yield of maize in precision nutrient management practices was mainly due to higher number of cobs (2.00), higher cob length and girth (20.64 cm and 7.04 cm), number kernel row^{-1} (42.09) and number of kernel cob^{-1} (710.83) (Table 2). The results are in conformity with the findings of Arunkumar *et al*. (2017) [4], Chandrakanth *et al.* (2017) [7] and Dapake *et al.* (2017) [9]. The enhanced values of yield attributing characters could be ascribed to the tendency of nitrogen in accelerating growth, photosynthetic activity and translocation efficiency for photosynthates in presence of increasing NPK rates. Further, higher grain and stover yield of maize was mainly due to better translocation of photosynthates from source to sink and higher growth attributing characters like higher number of leaves, leaf area and higher dry matter production and its accumulation into different parts of plant and yield attributing characters like, number of cob $plant^{-1}$, cob length and girth, number of kernels row^{-1} number of kernels cob^{-1}. These results are in accordance with the findings of Sreelatha *et al*. (2012) [21] and Biradar *et al*. (2013) [6] who indicated that application of nutrients based on the principles of SSNM enhanced the productivity of maize. Mohanty *et al.* (2015) [15], Ramanjit *et al*. (2015) [17] and Mallikarjuna *et al*. (2016) [14] who reported that, GreenSeeker based nitrogen management practices recorded significantly higher yield and yield attributes in rice, cotton, sweet corn and maize, respectively.

The higher values of above mentioned yield components were due to better growth parameters particularly total dry matter production which was significantly higher at harvest stage (439.8 and 429.0 g $plant^{-1}$, respectively) in STCR and SSNM based NPK management for target yield of 11 t ha^{-1}. The results are in conformity with Chandrakanth *et al*. (2017) [7], Arunkumar *et al*. (2017) [4], Dapake *et al.* (2017) [9], Sinha (2016) [20] and Biradar *et al*. (2013) [6] who observed that increase in NPK levels increased the dry matter production. Increase in dry matter production per unit area is a first step in achieving higher yield. Dry matter production during various growth stages of any crop is an important pre-requisite for higher yields as it signifies photosynthetic ability of the crop and also indicates other synthetic processes during developmental sequences.

C. Nitrogen use efficiency

Nitrogen use efficiency under different N management strategies for maize crop was estimated in terms of recovery efficiency (RE), agronomic efficiency (AE) and physiological efficiency (PE) are presented in Table 3.

A perusal of pooled data in Table 3 showed that, application of N fertilizer through SPAD-40, N_{25} recorded significantly higher (91.63 kg kg^{-1}) nitrogen use efficiency over rest of the treatments and it was on par with application of nitrogen based on GreenSeeker device and nitrogen management through SPAD sufficiency index 96-100 per cent (85.87 kg ka^{-1} and 85.69 kg kg^{-1}, respectively). This increase in NUE was mainly due to reduced N application in split doses according to crop demand in turn reduces the losses of N by various means. This was in accordance with Maiti *et al.* (2004) and Ghosh *et al*. (2013) in rice. No nitrogen use efficiency was observed under absolute control. Similar results of lower efficiencies was observed by Singh *et al*. (2002), due to more N losses from soil-plant system leading to low NUE, when N application is not synchronized with crop demand.

Achievable level of recovery efficiency was registered in GreenSeeker based nitrogen management (79.79%) over other treatments. Absolute control treatment recodes no recovery efficiency due to without application of fertilizer. Increased level of RE depends on crop demand for N, supply of N from indigenous sources, fertilizer rate, timing product and mode of application. Recovery efficiency depends on the congruence between plant demand and nutrient release from fertilizer and

is affected by the application method (amount, timing, placement and N form) and factors that determine the size of the crop nutrient sink (genotype, climate, plant density, abiotic/biotic stresses) Similar results were obtained by Peng and Cassman (1998) and Khurana *et al*. (2008) in wheat.
Agronomic efficiency (Table 3) is a product of nutrient recovery from mineral or organic fertilizer (RE) and the efficiency with which the plant uses each additional unit of nutrient (PE). It depends on management practices that affect RE and PE. Significantly higher (51.40 kg kg^{-1}) agronomic efficiency was obtained in application of nitrogen based on GeenSeeker method and it was on par with nitrogen management through SPAD-40, N_{25} (48.54 kg kg^{-1}). Better timing and splitting of fertilizer N applications during the season was probably the major reason to the increase in agronomic N-use efficiency. Similar result was noticed by Khurana *et al*. (2008) and Pasuquin *et al.* (2010). The higher AE was mainly due to lesser application of N fertilizer. This lower agronomic use efficiency was due to absence of fertilizer. Similar result was also observed by Gilkes *et al*. (2010).
The pooled analysis showed significantly higher physiological efficiency (53.37 kg kg^{-1}) under GreenSeeker based nitrogen management and it was followed by nitrogen management through SPAD-40, N_{25} (51.19 kg kg^{-1}), nitrogen management through SPAD-35, N_{25} (50.86 kg kg^{-1}), recommended dose of N as per package of practices (50.68 kg kg^{-1}) and STCR based N management for target of 11 t ha (49.71 kg kg^{-1}). Absolute control recorded no physiological efficiency due to absence of external fertilizer. These results clearly show that when fertilizer N is applied in right quantity and right time when crop can translate it's efficiently in to grain yield, higher fertilizer N use efficiency can expected (Peng and Cassman, 1998) and Mahajan *et al*. (2013) also reported STCR-IPNS technology ensures higher nutrient use efficiencies.

Table 1: Growth parameters of maize at harvest as influenced by precision nitrogen management practices through crop Sensors (Pooled data of 2016 and 2017)

Treatments	Plant height (cm)	Number of leaves	Leaf area (cm^2 $plant^{-1}$)	Dry matter production (g $plant^{-1}$)	SPAD readings
T_1	181.30	10.52	6836	321.7	37.31
T_2	184.50	11.55	8074	361.0	37.54
T_3	210.78	14.59	9188	406.8	40.50
T_4	183.65	11.00	7762	360.0	38.01
T_5	186.00	12.45	8425	372.7	38.66
T_6	194.17	13.57	8741	393.5	41.46
T_7	215.63	14.94	9480	419.1	42.28
T_8	218.82	15.07	9597	429.0	39.77
T_9	199.88	14.28	8767	402.4	37.03
T_{10}	223.86	15.37	9836	439.8	40.76
T_{11}	191.45	13.32	8562	374.6	40.90
T_{12}	168.73	9.74	6295	287.9	30.98
S.Em±	6.37	0.42	275	12.34	1.26
CD at 5%	18.68	1.22	806	36.20	3.70

T_1: Nitrogen management through SPAD sufficiency index 85-89% T_2: Nitrogen management through SPAD sufficiency index 90-95%
T_3: Nitrogen management through SPAD sufficiency index 96-100% T_4: Nitrogen management through SPAD-30, N_{25}
T_5: Nitrogen management through SPAD-35, N_{25} T_6: Nitrogen management through SPAD-40, N_{25}
T_7: GreenSeeker based nitrogen management T_8: Nitrogen management through SSNM for target of 11 t ha^{-1}
T_9: STCR based N management for target of 11 t ha^{-1} T_{10}: STCR based NPK management for target of 11 t ha^{-1}
T_{11}: Recommended dose of N as per package of practices T_{12}: Absolute control
RDF: 150: 75: 40, N, P_2O_5 and K_20 kg ha^{-1} FYM: 10 t ha^{-1}

Table 2: Yield and yield attributes of maize as influenced by precision nitrogen management practices through crop sensors (Pooled data of 2016 and 2017)

Treatments	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})	Number of cobs $plant^{-1}$	Cob length (cm)	Cob girth (cm)	Number of kernel row^{-1}	Number of kernel cob^{-1}
T_1	79.35	115.68	1.09	15.13	4.88	33.59	541.73
T_2	82.99	117.73	1.22	15.94	5.95	35.89	591.47
T_3	107.14	135.99	2.03	19.24	6.76	40.17	653.84
T_4	81.56	118.31	1.18	15.85	5.50	35.40	572.42
T_5	84.20	117.28	1.34	17.09	5.99	36.08	583.01
T_6	91.63	122.91	1.64	18.04	6.38	38.47	636.41
T_7	107.34	134.48	1.84	20.24	6.95	40.40	675.46
T_8	108.36	136.38	1.85	20.27	7.02	41.00	685.95
T_9	101.46	130.85	1.82	18.80	6.60	39.68	674.84
T_{10}	110.46	136.83	2.00	20.64	7.04	42.09	710.83
T_{11}	86.17	120.33	1.45	17.62	6.23	37.44	586.42
T_{12}	43.09	68.64	1.00	13.15	4.32	27.40	389.38
S.Em±	2.92	3.89	0.05	0.56	0.20	1.19	19.70
CD at 5%	8.56	11.40	0.14	1.65	0.58	3.48	57.79

T_1: Nitrogen management through SPAD sufficiency index 85-89% T_2: Nitrogen management through SPAD sufficiency index 90-95%
T_3: Nitrogen management through SPAD sufficiency index 96-100% T_4: Nitrogen management through SPAD-30, N_{25}
T_5: Nitrogen management through SPAD-35, N_{25} T_6: Nitrogen management through SPAD-40, N_{25}
T_7: GreenSeeker based nitrogen management T_8: Nitrogen management through SSNM for target of 11 t ha^{-1}
T_9: STCR based N management for target of 11 t ha^{-1} T_{10}: STCR based NPK management for target of 11 t ha^{-1}
T_{11}: Recommended dose of N as per package of practices T_{12}: Absolute control
RDF: 150: 75: 40, N, P_2O_5 and K_20 kg ha^{-1} FYM: 10 t ha^{-1}

Table 3: Nitrogen use efficiency (kg kg^{-1}) of maize as influenced by precision nitrogen management practices through crop sensors (Pooled data of 2016 and 2017)

Treatments	Nitrogen use efficiency (kg grain kg^{-1} N applied)	Recovery efficiency (%)	Agronomic efficiency (kg grain kg^{-1} N applied)	Physiological efficiency (kg grain kg^{-1} N uptake)
T_1	79.35	59.38	36.26	47.54
T_2	82.99	64.31	39.90	48.26
T_3	85.69	77.50	51.22	50.59
T_4	81.56	62.20	38.47	48.52
T_5	84.20	63.31	41.11	50.86
T_6	91.63	72.79	48.54	51.19
T_7	85.87	79.79	51.40	53.37
T_8	37.46	53.24	22.56	47.85
T_9	32.87	47.39	18.85	49.71
T_{10}	33.42	51.33	20.29	48.35
T_{11}	57.44	52.72	28.72	50.68
T_{12}	0.00	0.00	0.00	0.00
S.Em$\pm$	2.43	2.04	1.25	1.56
CD at 5%	7.13	5.99	3.66	4.58

T_1: Nitrogen management through SPAD sufficiency index 85-89% T_2: Nitrogen management through SPAD sufficiency index 90-95%
T_3: Nitrogen management through SPAD sufficiency index 96-100% T_4: Nitrogen management through SPAD-30, N_{25}
T_5: Nitrogen management through SPAD-35, N_{25} T_6: Nitrogen management through SPAD-40, N_{25}
T_7: GreenSeeker based nitrogen management T_8: Nitrogen management through SSNM for target of 11 t ha^1
T_9: STCR based N management for target of 11 t ha^{-1} T_{10}: STCR based NPK management for target of 11 t ha^{-1}
T_{11}: Recommended dose of N as per package of practices T_{12}: Absolute control
RDF: 150: 75: 40, N, P_2O_5 and K_20 kg ha^{-1} FYM: 10 t ha^{-1}

Conclusion

From the study, it can be concluded that application of NPK fertilizer through STCR and SSNM method for target yield of 11 t ha^{-1}, Nitrogen use efficiency in terms of recovery efficiency (RE), agronomic efficiency (AE) and physiological efficiency (PE) under different N management strategies for maize crop was recorded significantly higher when nitrogen applied based on SPAD and GreenSeeker tool. Therefore, nitrogen management through GreenSeeker and SPAD sufficiency index are the best precision nitrogen management practices in maize for realizing higher grain yield and higher nitrogen use efficiency with higher monetary advantage.

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