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EFFICIENT MANAGEMENT OF FERTILIZER NITROGEN IN SPRING MAIZE USING SPAD CHLOROPHYLL METER AND GREENSEEKER OPTICAL SENSOR

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ABSTRACT

Over-application of fertilizer nitrogen (N) in spring maize results in low fertilizer N use efficiency. Site specific need-based fertilizer N management in spring maize using chlorophyll meter (SPAD meter) and GreenSeeker optical sensor was compared with soil-test recommended N applications in field experiments conducted for two years during 2017 and 2018. Treatments consisted of different rates of N application based on SPAD and GreenSeeker sufficiency index approaches and soil-test based recommended N applications. The results showed that N application using SPAD based on sufficiency index of 0.95 and GreenSeeker based on 0.90 sufficiency index criteria not only produced significantly higher yields but also increased total N uptake by 10.7% to 15.0% than soil-test based fertilizer N recommendation with fertilizer N dose of 120 kg N ha^{-1}. Significantly higher N recovery and agronomic efficiencies were observed when N was applied using SPAD and GreenSeeker based sufficiency index approaches. The results of this study suggested that to avoid over application of N and to obtain high yields and N-use efficiencies in spring maize fertilizer N application should be guided by sufficiency index approach that indicate N deficiency or sufficiency for the crop.

Keywords: Chlorophyll meter (SPAD), GreenSeeker optical sensor, Nitrogen use efficiency, Sufficiency index

Full yield potential of spring maize (*Zea mays* L.) can only be achieved with application of adequate amount of fertilizer nitrogen (N). The existing soil test-based fertilizer N recommendations based on soil organic carbon content were established for wide geographical regions without considering spatial variability in soil N supply. The fixed time fertilizer N applications in soil test-based fertilizer N recommendations further restrict their efficiency as the plant demand for N varies with the soil properties, agronomic and soil management practices and climate. Commonly followed practice of over-application of fertilizer N to keep crop leaves dark green and avoid risk of N deficiency in maize often leads to N losses from the soil-plant system through leaching, denitrification or volatilization (Cassman *et al.,* 2002 and Abebe and Feyisa 2017). This practice leads to reduced fertilizer N use efficiency (NUE), which hardly exceeds 50 per cent in maize (Doberman *et al.,* 2003, Ladha *et al.,* 2016). Low NUE is attributed to lack of synchronization of N applications with N need patterns of the plants (Cassman *et al.,* 2002, Fageria and Baligar 2005). Determining the extent to which crops respond to additional N by monitoring N status helps in fine-tuning of N rates and timing of N applications. The need-based fertilizer N management approaches use tools such as chlorophyll meters and GreenSeeker optical sensors. The chlorophyll meter is also known as SPAD (soil plant analysis development) meter. Determining the chlorophyll content using SPAD meter, provides an opportunity to make need-based fertilizer N topdressing decisions in real time. The SPAD meter is a simple, quick and non-destructive method of estimating N content in terms of the chlorophyll content of maize leaves (Netto *et al.,* 2005, Uddling *et al.,* 2007, Singh *et al.,* 2015, Zhao *et al.,* 2016). The spectral properties measured using SPAD meter are highly reliable in differentiating N-optimum and N-deficient plants with 93% accuracy using a threshold level approach in maize (Piekielek *et al.,* 1995). The GreenSeeker optical sensor is also used to decide need-based fertilizer N applications while considering leaf greenness as well as the plant biomass. The GreenSeeker (NTech Industries, Inc., Ukiah, California, USA) is a widely used optical sensor that helps guide need-based N application decisions. The sensor generates data as Normalized Difference Vegetative Index (NDVI) and NDVI guided N applications adjust N dose while considering crop biomass and inherent soil N supply (Schmidt *et al.,* 2011). The best linear relationship between NDVI and grain yield are reported at V7 to V9 growth stages in maize (Ritchie *et al.,* 1986, Jagdeep-Singh and Varinderpal-Singh 2021). Among the various approaches of N management, sufficiency index (SI) approach (defined as SPAD/NDVI value of plot in question divided by that of well-fertilized reference plot) using spectral indices is commonly used

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to detect N deficiency or sufficiency in maize (Yu *et al.,* 2010) varieties varying in leaf color intensity. Highest maize yields were recorded by Varvel *et al.* (1997) and Sainz Rozas and Echeverrı´a (1998) using SPAD based SI value between 90 and 100% from V8 to R1 growth stage. Fertilizer N saving of 25-40 kg N ha^{-1} in contrast to recommended splits in rice crop was also reported by Bijay-Singh *et al.* (2003).

Therefore, a study for fine-tuning of fertilizer N program to actual needs of plant under field conditions, reducing the risk of yield-limiting N deficiencies or costly over- fertilizing by using a chlorophyll meter and GreenSeeker optical sensor was carried out.

MATERIALS AND METHODS

To study the effect of site-specific fertilizer N management using SPAD and GreenSeeker on spring maize yield and fertilizer N use efficiencies field experiment were conducted for two years during 2017 and 2018 at research farm, Department of Soil Science, Punjab Agricultural University, Ludhiana on a alkaline sandy loam soil (*Typic Ustipsamment*) and Krishi Vigyan Kendra, Gurdaspur on a alkaline silt loam soil (*Typic Haplustalf*). Soils of the experimental fields had physicochemical indices: pH 6.7 -7.5; EC 0.16-0.23 dS m^{-1}; soil organic carbon 4.2-6.5 g kg^{-1}; $KMnO_4$-extractable N 89-112 kg ha^{-1}; Olsen-P 19.0-21.0 kg ha^{-1}; and 1M ammonium acetate extractable-K 88-108 kg ha^{-1}. The experiments were laid out in a randomized complete block design with three replications.

Two field experiments were conducted for two years during 2017 and 2018 with spring maize hybrid cultivars ‘DKC-9108’ and ‘PMH-10’ at Research farm, Department of Soil Science, Punjab Agricultural University, Ludhiana and Krishi Vigyan Kendra, Gurdaspur sites respectively. The Ludhiana has a subtropical and semi-arid climate with the annual rainfall of 733 mm while the climate of Gurdaspur is sub-humid with an annual rainfall of 887 mm. The mean minimum and maximum temperatures of the region ranges from 15.8°C to 30.8°C during the experimentation (February to June). The experiments consist of eight fertilizer N treatments. The detail of the treatments is given below:

T1. No-N Control

T2. Soil test-based N applications (N applied in three equal splits at planting, knee high and pre tasseling stage)

T3. 30 kg N ha^{-1} at sowing + 30 kg N ha^{-1} based on sufficiency index approach whenever SPAD value of the test plot was <0.85 of the SPAD value of N_{rich} strip

T4. 30 kg N ha^{-1} at sowing + 30 kg N ha^{-1} based on sufficiency index approach whenever SPAD value of the test plot was <0.90 of the SPAD value of N_{rich} strip

T5. 30 kg N ha^{-1} at sowing + 30 kg N ha^{-1} based on sufficiency index approach whenever SPAD value of the test plot was <0.95 of the SPAD value of N_{rich} stripT6. 30 kg N ha^{-1} at sowing + 30 kg N ha^{-1} based on sufficiency index approach whenever NDVI value of the test plot was <0.85 of the NDVI value of N_{rich} strip

T7. 30 kg N ha^{-1} at sowing + 30 kg N ha^{-1} based on sufficiency index approach whenever NDVI value of the test plot was <0.90 of the NDVI value of N_{rich} strip

T8. 30 kg N ha^{-1} at sowing + 30 kg N ha^{-1} based on sufficiency index approach whenever NDVI value of the test plot was <0.95 of the NDVI value of N_{rich} strip

Sufficiency level was calculated by SPAD/NDVI value of the test plot divided by the SPAD/NDVI value of the over-fertilized reference (OFR) strip. A nitrogen rich plot was established by applying excess of fertilizer N (250 kg N ha^{-1} in 5 equal splits at 0, 38, 48, 58 and 68 days after sowing (DAS)) during the whole crop season to avoid N deficiency.

A basal dose of 26 kg P ha^{-1} as single super phosphate and 25 kg K ha^{-1} as potassium chloride was applied at the time of sowing. Spring maize was sown in the second week of February at 60 × 20 cm spaced east-west ridges made with bed planter for early emergence and good vigor.

The spectral properties of spring maize leaves were measured using SPAD meter and shoulder mounted GreenSeeker optical sensor. The spectral properties were measured at 10-day interval starting from 38 days after sowing (six leaf, V6) to 68 days after sowing (silking stage, R1). The SPAD meter readings were recorded with Minolta SPAD 502 for estimating leaf N by inserting the middle portion of the topmost fully expanded first leaf (index leaf) in the slit of the SPAD meter from randomly selected healthy fifteen plants. A shoulder mounted GreenSeeker optical sensor Model 505 (N tech Industries Inc., Ukiah, CA, USA) was used to record NDVI measurements from the crop canopy. The sensor readings were collected by holding the GreenSeeker at a height of about 1 m above the crop canopy at a walking speed of 0.5 m s^{-1}. Sensor height from the soil surface was increased proportionally as crop growth stage advances. The device measured canopy reflectance at red region (656 nm) and NIR region (774 nm) wavebands to calculate NDVI (Raun *et al.,* 2005) as follows:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Where NIR or red denotes reflectance in the near infrared and red bands

At maturity, the crop was harvested manually. Grain and stover yields were estimated from each plot from the net area of 8.4 m^2. Moisture content in the grains was determined immediately after threshing and drying subsamples in an oven at 65°C for 48h. The grain weight was expressed at 150 g kg^{-1} water content. Stover samples were air dried in an oven at 65°C till a constant dry weight was attained. The stover samples were pounded in Willey mill, passed through 1 mm sieve and stored for N analysis.

Among the various nitrogen use efficiency components, the recovery efficiency (RE) and agronomic efficiency (AE) in different fertilizer N treatments were calculated using the frame work of Baligar *et al.* (2001) as described below:

$$\text{RE (\%)} = \frac{\text{N uptake with fertilizer N applied-N uptake in control}}{\text{Fertilizer N applied}}$$

$$\text{AE (kg grain kg}^{-1}\text{ N)} = \frac{\text{Grain yield with applied N – Grain yield in control}}{\text{Fertilizer N applied}}$$

The experimental data was analyzed using Analysis of Variance (ANOVA) with Statistical Product and Service Solution, USA (SPSS 21). Mean comparisons were performed based on Duncan's multiple range test (DMRT) at 5% probability level of test differences between treatments means.

RESULTS AND DISCUSSION

Grain yield

Grain yield data of maize in different treatments in the field experiments conducted at Ludhiana and Gurdaspur with two spring maize cultivars as affected by fertilizer N topdressing using SPAD meter and GreenSeeker based NDVI SI approach are listed in Tables 1 and 2. The SI approach reliably expressed the ability of SPAD and GreenSeeker gadgets to detect N deficiencies in maize (Yu *et al.,* 2010, Ordonez *et al.,* 2015) in varieties varying in leaf color intensity. Three SI values of 0.80, 0.90 and 0.95 were evaluated using SPAD meter and NDVI measurements. Results showed significantly higher grain yield of both DKC-9108 and PMH-10 maize cultivars with 120 kg N ha^{-1} application following 0.95 SPAD-based SI criteria (T5) compared to soil test based fixed N splits. The plots receiving 90 kg N ha^{-1} each in 0.85 and 0.90 SPAD-based SI treatments always produced grain yield significantly lower than 0.95 SPAD-based SI and soil test-based fertilizer N application with application of 120 kg N ha^{-1}. Similar results were also found using NDVI SI approach of 0.90 with N applications of 120 kg N ha^{-1} over soil test-based N application. SI approach of 0.85 did not perform well in NDVI managed plots. Further, the NDVI based SI approach of 0.95 did not show any yield benefit even with an increased N application of 25% over T5 and T7 treatments. Similar results were reported during second year for both cultivars. Higher grain yields following SPAD-based SI of 0.95 and NDVI based 0.90 over soil test-based fixed N applications were due to the fact that the concept of SI approach takes into account factors such weather and soil N supply during crop growth to guide fertilizer N application which leads to high yield levels. These results are in accord with Schmidt *et al.* (2009) who reported NDVI quite suitable for N management in maize by accommodating temporal and spatial variability. Varvel *et al.* (1997) observed the highest grain yields of maize using SPAD-based SI

Table 1. Total fertilizer N application, grain yield, stover yield and total N uptake as influenced by need-based fertilizer N management using sufficiency index (SI) approach in spring maize cultivars in 2017

	Fertilizer Treatment	Total N applied (kg ha^{-1})	Grain yield (t ha^{-1})		Stover yield (t ha^{-1})		N uptake (kg ha^{-1})	
			DKC-9108	PMH-10	DKC-9108	PMH-10	DKC-9108	PMH-10
T1	No-N Control	0	4.76a$^{¥}$	4.77a	6.02a	5.92a	77.7a	76.4a
T2	Soil test based-N (3 equal splits)	120	7.69b	7.36b	8.86b	8.80c	151.8c	146.9c
T3	N_{30} basal +N at SPAD SI 0.85*	90	7.72b	7.65c	8.97b	8.53b	144.1b	139.9b
T4	N_{30} basal +N at SPAD SI 0.90	90	8.06c	8.14d	9.00b	8.86c	150.4bc	145.4bc
T5	N_{30} basal +N at SPAD SI 0.95	120	8.79d	8.67e	9.46c	9.24d	171.3d	166.6d
T6	N_{30} basal +N at NDVI SI 0.85	90	7.58b	7.50bc	8.76b	8.40b	142.7b	138.8b
T7	N_{30} basal +N at NDVI SI 0.90	120	8.78d	8.69e	9.38c	9.31d	168.0d	169.3d
T8	N_{30} basal +N at NDVI SI 0.95	150	8.81d	8.68e	9.36c	9.32d	169.5d	167.4d

*30 kg N ha^{-1}when ever spectral properties of leaf indicate sufficiency level below the threshold sufficiency index (SI)
¥Means within a column followed by different letters are significantly different at *p< 0.05* by Duncan's multiple range test (DMRT)

Table 2. Total fertilizer N application, grain yield, stover yield and total N uptake as influenced by need-based fertilizer N management using sufficiency index (SI) approach in spring maize cultivars in 2018

	Fertilizer Treatment	Total N applied (kg ha^{-1})	Grain yield (t ha^{-1})		Stover yield (t ha^{-1})		N uptake (kg ha^{-1})	
			DKC-9108	PMH-10	DKC-9108	PMH-10	DKC-9108	PMH-10
T1	No-N Control	0	4.63a¥	4.68a	6.10a	5.79a	78.6a	78.5a
T2	Soil test based-N (3 equal splits)	120	7.53b	7.59b	8.70b	8.75c	152.5c	148.3b
T3	N_{30} basal +N at SPAD SI 0.85*	90	7.50b	7.45b	8.82b	8.64bc	139.0b	141.2b
T4	N_{30} basal +N at SPAD SI 0.90	90	7.99c	7.95c	8.87b	8.88c	149.1bc	149.2b
T5	N_{30} basal + N at SPAD SI 0.95	120	8.71d	8.60d	9.63c	9.46d	170.3d	167.0c
T6	N_{30} basal + N at NDVI SI 0.85	90	7.59b	7.55b	8.47b	8.45b	139.6b	142.3b
T7	N_{30} basal + N at NDVI SI 0.90	120	8.73d	8.69d	9.40c	9.37d	169.5d	170.6c
T8	N_{30} basal + N at NDVI SI 0.95	150	8.77d	8.72d	9.38c	9.33d	169.9d	170.4c

*30 kg N ha^{-1}when ever spectral properties of leaf indicate sufficiency level below the threshold sufficiency index (SI)
¥Means within a column followed by different letters are significantly different at $p< 0.05$ by Duncan's multiple range test (DMRT)

approach than locally recommended practices. Ritchie *et al.* (1997) noted significant maize yield decline when fertilizer N was managed following SPAD-based SI value lower than 0.90.

Stover yield

Different fertilizer N management treatments exerted almost similar effect on spring maize stover yield as it was recorded for the grain yield (Tables 1 and 2). The stover yield increased significantly in various treatments compared to the no-N control. A significant N response was observed when N applications were guided using SPAD SI of 0.95 and NDVI sufficiency index of 0.90 over the soil-test based N recommendation. No significant increase in stover yield was observed with fertilizer N more than 120 kg ha^{-1} in both years. Therefore, the observed pattern of stover yields supported the earlier findings on grain yield which indicated higher grain yields of spring maize were obtained by using SPAD meter and NDVI based SI approach.

Total N uptake

Results in Tables 1 and 2 revealed that total N uptake by spring maize was significantly increased with N application compared to the control. The treatments T5 (30 kg N ha^{-1} basal + N topdressed at SPAD SI 0.95) and T7 (30 kg N ha^{-1} basal + N topdressed at NDVI SI 0.90) in which application of 120 kg N ha^{-1} resulted in total N uptake of 166.6 to 171.3 kg N ha^{-1}, and was 10.7 to 15.0% higher than soil-test based fertilizer N recommendation. Interpretatively, a major part of the applied fertilizer N in soil-test based fertilizer N treatment was lost by different pathways from the soil-plant system. In case of SPAD and NDVI-based treatments, fertilizer N was applied when it was needed

Table 3. Nitrogen recovery efficiency (%) and agronomic efficiency (kg grain kg^{-1}N applied) as influenced by need-based N management using sufficiency index (SI) approach in spring maize cultivars during 2017

	Fertilizer Treatment	Total N applied (kg ha^{-1})	Recovery efficiency of N		Agronomic efficiency of N	
			DKC-9108	PMH-10	DKC-9108	PMH-10
T1	No-N Control	0	-	-	-	-
T2	Soil test based-N (3 equal splits)	120	61.9a¥	58.8a	24.4a	21.6a
T3	N_{30} basal +N at SPAD SI 0.85*	90	73.9bc	70.6b	32.9d	32.0cd
T4	N_{30} basal +N at SPAD SI 0.90	90	80.8d	76.7c	36.6e	37.4e
T5	N_{30} basal + N at SPAD SI 0.95	120	78.0cd	75.1c	33.6d	32.5d
T6	N_{30} basal + N at NDVI SI 0.85	90	72.2b	69.3b	31.3c	30.4c
T7	N_{30} basal + N at NDVI SI 0.90	120	75.3bc	77.4c	33.5d	32.7d
T8	N_{30} basal + N at NDVI SI 0.95	150	61.2a	60.7a	27.0b	26.1b

*30 kg N ha^{-1}when ever spectral properties of leaf indicate sufficiency level below the threshold sufficiency index (SI)
¥Means within a column followed by different letters are significantly different at $p< 0.05$ by Duncan's multiple range test (DMRT)

Table 4. Nitrogen recovery efficiency (%) and agronomic efficiency (kg grain kg^{-1}N applied) as influenced by need-based N management using sufficiency index (SI) approach in spring maize cultivars during 2018

	Fertilizer Treatment	Total N applied (kg ha^{-1})	Recovery efficiency of N		Agronomic efficiency of N	
			DKC-9108	PMH-10	DKC-9108	PMH-10
T1	No-N Control	0	-	-	-	-
T2	Soil test based-N (3 equal splits)	120	61.9a[¥]	58.8a	24.4a	21.6a
T3	N_{30} basal +N at SPAD SI 0.85*	90	73.9bc	70.6b	32.9d	32.0cd
T4	N_{30} basal +N at SPAD SI 0.90	90	80.8d	76.7c	36.6e	37.4e
T5	N_{30} basal + N at SPAD SI 0.95	120	78.0cd	75.1c	33.6d	32.5d
T6	N_{30} basal + N at NDVI SI 0.85	90	72.2b	69.3b	31.3c	30.4c
T7	N_{30} basal + N at NDVI SI 0.90	120	75.3bc	77.4c	33.5d	32.7d
T8	N_{30} basal + N at NDVI SI 0.95	150	61.2a	60.7a	27.0b	26.1b

*30 kg N ha^{-1}when ever spectral properties of leaf indicate sufficiency level below the threshold sufficiency index (SI)
¥Means within a column followed by different letters are significantly different at $p< 0.05$ by Duncan's multiple range test (DMRT)

by the crop, which should result in reduced losses and high N use uptake. These results are in accordance with those reported by Varvel *et al.* (1997) who observed more N uptake with minimum N loss using with SPAD based SI approach in maize.

Recovery and agronomic efficiency of applied nitrogen

The data as listed in Tables 3 and 4 showed that the treatments in which fertilizer N was applied following SPAD and NDVI based SI approach produced significantly higher recovery efficiency (RE) over soil test-based fertilizer N recommendation with the exception of T8. The RE of 76.7 to 80.8% was observed in SPAD SI 0.90 (T4), followed by 73.4 to 78.0 per cent in T5 (30 kg N ha^{-1} basal + N topdressed at SPAD SI 0.95) and T7 (30 kg N ha^{-1} basal + N topdressed at NDVI SI 0.90) treatments. Similarly, maximum AE of 36.3 to 37.4 kg grain kg^{-1} N was obtained in T4 followed by 32.5 to 34.2 kg grain kg^{-1} N in SPAD SI 0.95 and NDVI SI 0.90 treatments. The higher N recovery efficiency and agronomic efficiencies recorded with lower N rate of 90 kg N ha^{-1} in the treatment T4 are not acceptable due to significantly lower grain yields in this treatment as compared to T5 and T7 treatments. It proves that time of fertilizer N application in SPAD based (T5) and NDVI-based (T7) treatments was better synchronized with N pattern of the crop than when 120 kg N ha-1 was applied in three equal splits at key growth stages of crop. These results are in consonance with Attia *et al.* (2015) who found greater nitrogen use efficiency using SPAD meter technology in maize, Varvel *et al.* (1997) and Kitchen *et al.* (2010) found higher nitrogen use efficiency using NDVI based N management in maize.

It can be concluded from the results of this study that the real time demand driven fertilizer N management using SPAD meter and GreenSeeker NDVI using in SPAD SI 0.95 and NDVI SI 0.90 respectively, produced significantly higher grain yield and N uptake than exiting soil test based fixed time N recommendation for spring maize cultivars and consequently resulted in improved nitrogen use efficiency.

Authors' contribution

Conceptualization of research work and designing of experiments (JS, VPS); Execution of field/lab experiments and data collection (JS); Analysis of data and interpretation (JS, VPS); Preparation of manuscript (JS).

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