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Precision nitrogen management in maize cultivars under variable growing environments: Effects on plant growth, normalised difference vegetation index and leaf nitrogen

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ABSTRACT

Fine tuning the nitrogen (N) recommendations, i.e. appropriate rate and time of N fertilizer application is an important factor for enhancing the growth and quality performance of maize cultivars and reducing N losses. Studies have shown that the normalised difference vegetation index (NDVI) and soil plant analysis development (SPAD) values were highly related with leaf N content of maize (*Zea mays*) and can sufficiently quantify the N requirements of maize plants. This study was conducted at New Delhi during rainy season of 2014-15 to determine the effects of two maize cultivars (PEEHM 5 and PC 3), three planting dates (July 9, July 24 and August 7) and four N rates [Control (0 kg N ha^{-1}), 30 kg N ha^{-1} basal + 30 kg N ha^{-1} when SPAD ≤ 37.5 till silking Chlorophyll meter based (CMB), 30 kg N ha^{-1} basal + 30 kg N ha^{-1} when SPAD ≤ 37.5 at knee-high, pre-tasseling, silking Chlorophyll meter based stage-wise (CMBSW) and soil test crop response based (STCRB, 160 kg N ha^{-1})] on different growth and quality characteristics of maize under north Indian conditions. Among plant characteristics, NDVI, SPAD value, leaf N content, total dry matter at maturity and leaf area index (LAI) were significantly higher in early planting dates, *i.e.* July 9 and CMB N treated crop than others at all the growth stages of maize. SPAD value recorded at tasseling stage were significantly correlated with estimated leaf N content and NDVI value at tasseling stage and total dry matter produced at maturity across the treatments.

Key words : Leaf N, maize cultivars, NDVI, N fertilizer, SPAD

INTRODUCTION

Maize (*Zea mays* L.) is now the highest producing cereal crop of world, growing over a wide range of agro-climatic variations, and serving as staple food for millions of people throughout the world and an important animal feed (Sharma and Dass, 2012; Ghosh et al., 2017; Kumari et al., 2017). Moreover, it contributes to the ethanol production and forms raw material for several industrial products (Ghosh et al., 2016). In India, maize contributes nearly 9% to the national food grain production and constitutes a quality feed for poultry and animals (Dass et al., 2015a). Despite, its economic importance for food, feed and industrial products, concerns exist in maize cultivation, particularly related to nutrient management. Among various agricultural inputs, fertilizers contribute about 30–50% towards yield performance (Stewart, 2002; Dass et al., 2015b; Joshi et al., 2018). Of late, growing awareness about impaired soil health, declining or stagnating productivity growth and decreasing nutrient-use efficiency (NUE) are compelling the farmers to use higher levels of fertilizers, mostly N and P fertilizers, particularly during the last two decades leading to over mining of other major, secondary and micro-nutrients (Dass et al., 2014a). Besides this, environmental pollution and global warming are the other serious issues related to existing nutrient management practices (Dass et al., 2014 b), especially so for N management with a low recovery efficiency.

N is a major yield determining factor required for maize (Shanti et al., 1997). Inefficient N fertilization in maize production system causes excessive nitrate levels in groundwater and leachate and N-induced hypoxia in estuarine areas from agricultural sources (McIsaac et al., 2002). N leaching losses increased and use efficiency decreased when fertilizer application rates exceeded crop N requirements (Van Es et al., 2002). N fertilizer application in 1-3 doses on the basis of soil test value is one of the widely followed approaches. However, the accuracy of this method is limited due to extensive sampling requirement in a short period of time (Ma and Dwyer, 1999) and high leaching losses in humid areas. Thus, precise application of optimum dose of N fertilizer according to crop demand is a compelling need to reduce losses and increasing efficiency (Ostergaard, 1997; Dass et al., 2014a, b). Two of such precision technologies, among many, namely, Normalized Difference Vegetation Index (NDVI) and chlorophyll (SPAD) measurement are widely used spectral indices involving optical sensing due to their ease of operation and effectiveness. NDVI measurements are related to reflectance by crop canopy in the visible (VIS) (400-700 nm) and near infrared (NIR) (700-1300 nm) spectral light bands. The NDVI value is calculated using the following equation:

$$NDVI = (NIR - VIS)/ (NIR + VIS)$$

The visible light reflectance by the crop canopy is primarily dependent on chlorophyll content of leaves (Campbell, 2002) and thus, greater leaf area and green plant biomass levels result in higher reflectance and higher subsequent NDVI values. Ercoli et al. (1993) reported a strong linear relationship between leaf chlorophyll concentration and leaf nitrogen (N) concentration. A good relationship has been documented between plant NDVI and plant N status (Rui et al., 2009; Rambo et al., 2010). Values from the chlorophyll soil plant analysis development (SPAD) meter (Minolta Camera Co., Osaka, Japan) are highly correlated with the N status of crops such as corn (*Zea mays* L.) (Blackmer and Schepers, 1995) because chlorophyll content depends on N supply (Pandey et al., 2000). Thus, a study involving comparative analysis of SPAD meter based N application with soil test value method and their effect on growth and relationship with spectral indices is imperative for making valid recommendations. Agronomic and physiological performances of maize vary greatly with different maize cultivars. Odeleye and Odeleye (2001) also reported that maize varieties differ in their growth characters, yield and its components. PEEHM 5 and PC 3 are two maize cultivars recently developed by IARI and recommended for cultivation in northern, north-east hill region, and southern India. Hence, an attempt has been made to evaluate the performances of these varieties under precise N management strategies. Planting dates also influence production and yield of maize due to alteration climatic elements (rainfall, temperature and relative humidity). Sárvári and Futó (2000) reported that each hybrid has an optimum sowing date, deviation from which (early or late sowing than optimum), can result in severe yield loss. These findings are enough reasonable to investigate the responses of different maize varieties to different growing environments to determine optimum planting conditions. Very few, if any, studies have characterized growth and yield of maize cultivars PEEHM 5 and PC 3 in response to changing environmental conditions resulting from a range of planting dates under Northern India conditions. Keeping all in view the present investigation was carried out evaluate the effect of planting dates and N application rates on growth and quality of maize cultivars using crop canopy sensors.

MATERIALS AND METHODS

An irrigated field experiment was conducted at the research farm of Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi (28°38'23" N, 77°09'27"E and 228.6 m above MSL of Arabian sea) during *kharif* season 2014-15 on sandy loam soil. During the crop growth period in *kharif* season of 2014-15, mean weekly maximum and minimum temperature, weekly maximum and minimum relative humidity, sun shine hours per day and evaporation were 34.23°C, 22.79°C, 84.81%, 53.24%, 5.6 hrs and 6 mm day^{-1}, respectively. Crop season received rainfall of 56.38 mm with a weekly average of 3.13 mm. The experimental design was split plot with three replications and 72 plots. Plots consisted of seven rows (60 cm inter-row spacing) and 4.8 m long with 3 m width.

Initial soil test indicated mean values of soil pH of 7.4, organic carbon of 0.58%, available phosphorus of 18.7 kg ha^{-1}, and available potassium of 262 kg ha^{-1}. Treatments consisted of 24 combinations with two varieties *viz.* hybrid variety PEEHM 5 and composite variety Pusa Composite 3 (PC 3) and three planting dates *i.e.* July 9, July 24 and August 7 in the main plot and four nitrogen application rates *i.e*. control (0 kg N ha^{-1}) (control), 30 kg N ha^{-1} basal + 30 kg N ha^{-1} when SPAD ≤ 37.5 till silking (CMB) , 30 kg N ha^{-1} basal + 30 kg N ha^{-1} when SPAD ≤ 37.5 at knee-high, pre-tasseling, silking (CMBSW) and soil test crop response based (STCRB, 160 kg N ha^{-1}) in sub plot.

Standard package and practices were followed to raise a healthy maize crop except treatments. Maize seeds (properly treated with insecticides) were dibbled on flat beds prepared manually by using 20 kg seed ha^{-1}. Nitrogen in the form of urea, phosphates as single super phosphate (SSP), potash as muriate of potash (MOP) were applied at the time of land preparation as basal. Subsequent N fertilizer after basal application was broadcasted based on SPAD meter reading taken according to treatment requirements. For zinc application, zinc sulphate ($ZnSO_4$) was used. To control weeds, atrazine @1.0 kg a.i. ha^{-1} as pre-emergence herbicide was sprayed. Four post sowing irrigations and one extra irrigation for PC 3 were applied in maize to supply the adequate moisture at different stages for each planting date. Relative chlorophyll (SPAD values) content were measured in upper most fully expanded maize leaves with Minolta SPAD-520 meter (Konica Minolta Sensing, Inc., Japan) from at least ten plants from second row in maize crop at 10-day interval and also at knee-high, tasseling and maturity stages averaged out. The NDVI measurements were taken with the Green Seeker™ Handheld Optical Sensor Unit (N Tech Industries, Inc., USA) in the central rows of all plots and the instrument gives out digital values of NDVI. To determine total dry matter accumulation (DMA) in maturity, five plants from the sampling rows, *i.e.* second rows from boarder were uprooted, separated into different plant parts, air dried in shade for five days and finally oven dried at 70 ± 2°C till a constant weight was recorded. Total dry matter at maturity was calculated by using following formulae:

Total dry matter at maturity = [leaf dry weight + stem dry weight + cob (grain + rachis) weight + husk weight]

The leaf area was measured from the leaves of five sampled plants at knee-high and tasseling stages by using the leaf area meter (Model LI-COR-3100) and leaf area index was worked out as leaf area per unit land area.

N content in leaves of maize plants was estimated following standard procedure (Rana et al., 2014). The data relating to each parameter of maize were analyzed by technique of ‘analyses of variance’ for split-plot design (Rana et al., 2014). The standard error of mean (SEm±) and critical differences (CD) values at 5% level of significance were calculated for comparing the differences among treatment means.

RESULTS AND DISCUSSION

In several past investigations, different maize genotypes have been reported to vary in ecological amplitude of adaptability and ability to intercept and use growth factors efficiently. Thus, they exhibit different growth, vigour and quality performances. Accordingly, in present experiment, an interpretation of facts indicated that hybrid variety PEEHM 5 recorded significantly higher amount of total DMA at maturity and 284 cm^2 per plant more leaf area at knee-high stage than composite PC 3. But at tasseling stage PC 3 recorded more leaf area (Tables 1, 2). Sharifi et al. (2009) also reported significant differences among different maize cultivars (including hybrids) in terms of

DMA, above-ground biomass and grain yields due to differences in maize cultivars to stomata conductance value and in partitioning of photosynthetic materials towards economic yield (Ghosh et al., 2017; Kumari et al., 2017). During initial growth stages (seedling and knee-high), PEEHM 5 exhibited faster growth rate and higher N uptake. This resulted in significantly higher leaf N content in PEEHM 5 than PC 3 at early growth stages. However, at tasseling and maturity stages, variety PEEHM 5 recorded significantly lower leaf N content because N was spent to produce carbohydrate in grain, and grain yield of the variety PEEHM 5 was significantly higher compared to PC 3. Thus, the difference in leaf N on an average between the varieties was nullified because composite PC 3 recorded poor above ground biomass (leaf + stem) and hence lower leaf N content during early stages of crop growth while at later stages it rapidly increased the same containing more leaf N than PEEHM 5. As a consequence, SPAD values did not vary significantly among the cultivars (Table 2). More amount of vegetation, or active photosynthetic tissue, will increase the amount of light absorbed in the red spectrum and light reflected in the near-infrared spectrum, and thus NDVI value (Federer et al., 1966). Correspondingly, PEEHM 5 showed significantly higher NDVI value at knee-high stage.

Table 1. Effect of varieties, planting dates and chlorophyll meter based N application on total dry matter at maturity, leaf N content, NDVI and SPAD meter readings of maize at knee-high and tasseling stages

Treatment	Dry matter at maturity (g plant^{-1})	Leaf N content (%)			NDVI		SPAD values	
		Knee high	Tasseling	Maturity	Knee-high	Tasseling	Knee-high	Tasseling
Varieties								
PEEHM 5	189.2	1.76	2.28	1.13	0.55	0.61	40.05	41.17
Pusa Composite 3	180.9	1.66	2.38	1.18	0.46	0.64	38.52	42.21
SEm (±)	1.36	0.04	0.03	0.01	0.00	0.01	0.55	0.67
CD (P=0.05)	4.08	0.12	0.09	0.04	0.01	0.03	1.64	2.00
Planting dates								
July 9	192.9	1.86	2.40	1.19	0.59	0.68	41.44	43.46
July 24	187.6	1.70	2.33	1.15	0.50	0.63	39.01	41.62
August 7	174.5	1.58	2.27	1.13	0.43	0.56	37.40	39.99
SEm (±)	1.67	0.05	0.04	0.02	0.00	0.01	0.67	0.82
CD (P=0.05)	4.99	0.14	0.12	0.05	0.01	0.04	2.00	2.45
Nitrogen								
Control	150.0	1.21	1.64	0.80	0.35	0.47	19.65	23.38
CMB	212.3	2.00	2.62	1.29	0.60	0.70	48.15	50.19
CMBSW	187.9	1.81	2.54	1.27	0.54	0.66	44.87	46.69
STCRB	189.9	1.84	2.52	1.26	0.54	0.67	44.46	46.50
SEm (±)	1.84	0.03	0.05	0.03	0.01	0.01	0.68	0.65
CD (P=0.05)	5.29	0.07	0.14	0.07	0.02	0.03	1.97	1.88

CMB: Chlorophyll meter based N application up to silking i.e. 30 kg ha^{-1} N basal + 30 kg ha^{-1} N top-dressed each time leaf SPAD value falls to ≤ 37.5; CMBSW: Chlorophyll meter based N application stage-wise i.e. 30 kg ha^{-1} N basal + 30 kg N top-dressed each at knee high, pre-tasseling and silking stages when SPAD value falls to ≤ 37.5; STCRB: Soil test crop response based N application.

Table 2. Effect of varieties, planting dates and chlorophyll meter based N application on leaf area and LAI of maize at knee-high and tasseling stages

Treatment	Leaf area (cm^2 $plant^{-1}$)		LAI	
	Knee-high	Tasseling	Knee-high	Tasseling
Varieties				
PEEHM 5	5088	5718	4.24	4.76
Pusa Composite 3	4520	6000	3.76	5.00
SEm (±)	88.4	63.1	0.04	0.05
CD (P=0.05)	265.2	189.2	0.22	0.16
Planting dates				
July 9	4921	6299	4.10	5.25
July 24	4909	5977	4.09	4.98
August 7	4582	5300	3.81	4.42
SEm (±)	108.3	77.3	0.05	0.06
CD (P=0.05)	324.7	231.8	0.27	0.19
Nitrogen				
Control	3450	4127	2.88	3.44
CMB	5869	6801	4.89	5.67
CMBSW	4919	6261	4.10	5.22
STCRB	4979	6246	4.15	5.21
SEm (±)	147.8	111.1	0.06	0.09
CD (P=0.05)	425.6	320.1	0.36	0.27

CMB: Chlorophyll meter based N application up to silking i.e. 30 kg ha^{-1} N basal + 30 kg ha^{-1} N top-dressed each time leaf SPAD value falls to ≤ 37.5; CMBSW: Chlorophyll meter based N application stage-wise i.e. 30 kg ha^{-1} N basal + 30 kg N top-dressed each at knee-high, pre-tasseling and silking stages when SPAD value falls to ≤ 37.5; STCRB: Soil test crop response based N application

Early planting on July 9 resulted in vigorous growth and higher biomass yield (leaf area) due to favourable climatic conditions. Meteorological data revealed that August 7 planted crop experienced considerably low relative humidity in comparison to July 9 and July 24 (Mean average daily RH during the respective crop growth periods: 66.4, 69 and 70.3%) planted crop at the time of tasseling which may be a probable explanation for low grain yield, and hence total DMA at maturity. NDVI value was recorded significantly higher in July 9 sown plants at all growth stages than other planting dates due to higher canopy cover (Trout et al., 2008). N content in leaf was also significantly higher in crop sown on optimum time than delayed planting because of higher N uptake due to higher root length at knee-high stage (July 9: 225.4 cm, July 24: 219.3 cm and August 7: 195.3 cm) and conducive moisture regimes (Total rainfall during 16-23 July, 2014: 133 mm compared to 14–23 August, 2014: 0 mm) that enabled the plants to explore much greater volume of resource poor soil and capture nutrients and also favourable precipitation helped in mineralization of organic matter. Higher leaf N content resulted in significantly higher SPAD value in early planted crop (July 9 and July 24) at all the growth stages.

Chlorophyll meter based N (CMB) application significantly increased total dry matter production at maturity and LAI at vegetative growth phase than other N treatments due to split N fertilization as per crop demand limiting the chances of N deficiencies. Continuous supply and uptake of N in CMB resulted in significantly higher leaf N content, SPAD and NDVI values due to greater canopy cover, chlorophyll content and vigorous plant growth compared to control and STCRB N. Dass et al. (2014), in line with our findings, also concluded that chlorophyll meter based N gives higher yield than STCR based N application, with considerable saving on N fertilizer.

Relationship among different parameters have been studied in an attempt to discuss and clarify the behavioural trend of corn genotypes under different environmental conditions finding cause and effect criteria. Higher nutrient uptake and concentration may attribute to higher leaf area and biomass production. Total DMA at maturity was significantly and positively correlated with LAI and leaf N content at tasseling, and both NDVI and SPAD value measured at tasseling stage were significantly (critical value of r at p=0.05 with d.f. 3 is 0.878) correlated with Leaf N content and LAI at tasseling stage and total DMA at maturity across the treatments. However, regression analyses revealed that total DMA at maturity had a linear relationship with LAI recorded at tasseling stage, while the relationship between NDVI and LAI at tasseling stage and SPAD value recorded and leaf N content at tasseling stage is quadratic (higher r^2 value than linear relationship) considering all treatments (Table 3; Figs. 1, 2 ,3).

Table 3. Correlation between total dry matter at maturity, NDVI, SPAD, leaf N content and LAI at tasseling stage across the treatments

	Total dry matter at maturity	LAI at tasseling	Leaf N content at tasseling	NDVI at tasseling	SPAD value at tasseling
Total dry matter at maturity	1				
LAI at tasseling	0.952*	1			
Leaf N content at tasseling	0.902*	0.967*	1		
NDVI at tasseling	0.927*	0.992*	0.944*	1	
SPAD value at tasseling	0.927*	0.970*	0.997*	0.944*	1

*p≤0.05 (two-tailed test)

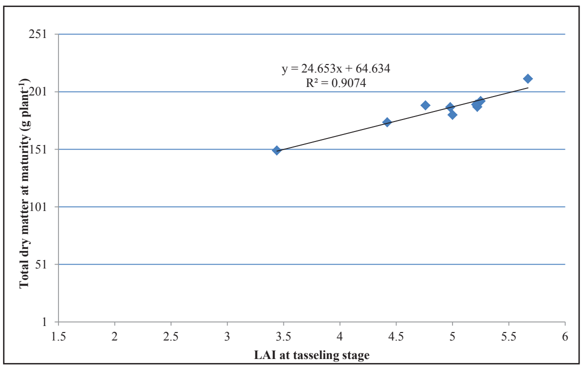

Fig. 1. Correlation between LAI at tasseling and total DMA at maturity

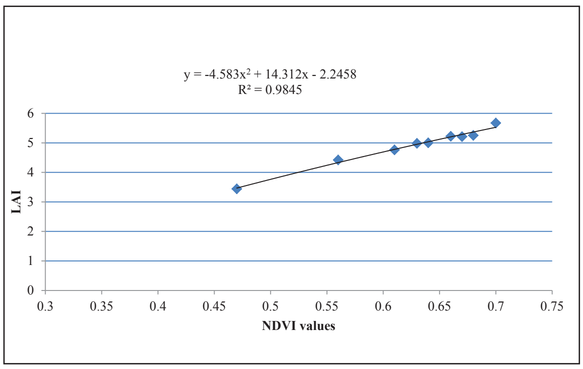

Fig. 2. Correlation between NDVI and LAI at tasseling stage

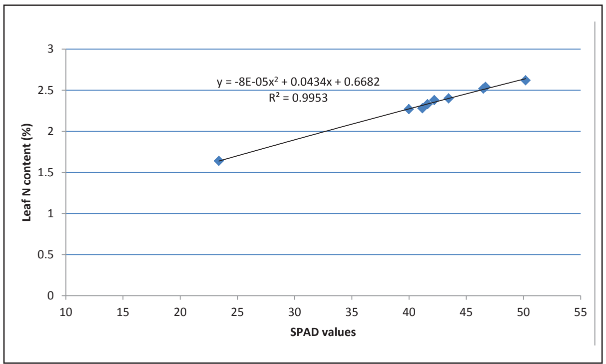

Fig. 3. Correlation between SPAD value and leaf N content at tasseling stage

Overall, it could be concluded that plant characteristics, NDVI, SPAD value, leaf N content, total dry matter at maturity and leaf area index were significantly higher in early planting dates (July 9) and CMB N [30 kg N ha^{-1} basal + 30 kg N ha^{-1}at SPAD value ≤ 37.5 till silking] treated crop. SPAD values were significantly correlated with estimated leaf N content indicating that leaf N contents in maize leaf can be estimated non-destructively by using SPAD meter (Chlorophyll meter).

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