Maize Journal (April 2021) 10(1): 46-52
RESEARCH PAPER

Precision nutrient management influences growth, yield attributes and yield of *kharif* maize (*Zea mays* L.)

Manjunath H.[2] · S. L. Jat[1] · C. M. Parihar[2] · B. R. Meena[2] · Radheshyam[2] · Praveen V. Kadam[2] · Bhupender Kumar[1] · Bheru Lal Kumhar[3]

Abstract: An investigation was conducted during *kharif* season of 2016 for exploring the influence of precision nutrient management on the growth and yield of maize in sandy loam soil at research farm of ICAR–IARI, New Delhi. The results of the study indicated that growth parameters (plant height, dry matter accumulation and leaf area index) and yield attributes (cobs/ha, cob length, grains/row and grains/cob) in maize were improved significantly with precision nutrient management practices. The Soil-Test Crop Response (STCR)-based precision nutrient management practice increased grain yield of maize to the tune of 2.9-122.7 per cent over control and other precision nutrient management practices. The grain yield of maize in STCR-based nutrition was on par with green seeker-based nutrition in 33 per cent basal N+GS guided at knee high and tasseling (T_5), 60 per cent basal N + GS guided at tasseling (T_8) and 70 per cent basal N + GS guided at tasseling (T_9). This was followed by 30–35 per cent basal N + 30–35 per cent N at 25 days after sowing (DAS)+GS guided at the tasseling stage. Thus, it was concluded that application of 33 per cent basal N + GS guided N or 60–70 per cent basal N + GS guided N at tasseling or 30–35 per cent basal N + 30–35 per cent N at knee high + GS guided at tasseling stage could be a better choice for enhancing growth, yield attributes and yield in maize production.

Keywords: Maize · Precision nitrogen management · Green Seeker · Yield attributes

✉ S. L. Jat: sliari2016@gmail.com

[1]ICAR–Indian Institute of Maize Research, New Delhi-110012, India

[2]ICAR–Indian Agricultural Research Institute, New Delhi-110012, India

[3]Agricultural University, Kota-325001, Rajasthan, India

Received: 10 December 2020/ Accepted: 17 March 2021

Introduction

Maize (*Zea mays* L.) also known as “Queen of cereals”, is the world’s third most important cereal after wheat and rice and is grown in different agro-ecological regions. In addition to staple food for human beings and quality feed for animals, maize serves as a basic raw material to thousands of industrial products *viz*., starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, film, textile, gum, package and paper industries. In India, it is mainly grown in the rainy (*kharif*) season, which contributes about 70 per cent of the total maize production of the country. As a fodder and grain crop, it is extensively grown in Uttar Pradesh, Rajasthan, Madhya Pradesh, Bihar and Karnataka and now it is gaining popularity as maize, for crop diversification perspective, is being considered as a suitable alternative to rice in the unsustainable rice-wheat cropping system belt of the Indo Gangetic plains. Besides abiotic and biotic stresses, poor soil fertility (including micronutrient deficiencies) and low nutrient use efficiency are among the most important factors limiting maize productivity and yield stability in India (Yadav *et al*., 2016).

Nitrogen is one of the most important nutrients required in crop production. It is subjected to losses in different forms like ammonia, nitrate, nitrous oxide through different processes such as denitrification, volatilization and leaching losses which cause environmental pollution like eutrophication of water bodies, increase in nitrate content in groundwater etc. Nitrous oxide has 298 times more global warming potential than carbon dioxide and its emissions are due to poor nitrogen management in the intensive crop production system (Prasad and Shivay, 2019). The potential for enrichment of ground and surface waters with nitrates also increases with excessive N fertilizer applications causing eutrophication of aquatic ecosystem and methemoglobinemia in infants (blue baby syndrome) (Jat *et al*., 2016). However, insufficient N availability to crop results in low yields and significantly reduced profits compared to a properly fertilized crop. Efficient nutrient management programmes supply plant nutrients in adequate quantities to sustain maximum crop productivity and profitability while minimizing the environmental impacts of nutrient use (Jat *et al*., 2013). Ensuring optimum nutrient availability through effective nutrient management practices requires knowledge of the interactions between the soil, plant and environment. The use of some tools for in-season N management like Soil Plant Analysis Development (SPAD)/ chlorophyll meter, Green Seeker, Site-Specific Nutrient Management (SSNM) through Soil-Test Crop Response (STCR) or Nutrient Expert helps in fulfilling the crop nutrient requirement with less environmental footprints apart from higher crop productivity and profitability of maize-based production systems in India (Kumar *et al*., 2014; Kumar *et al*., 2015; Pooniya *et al*., 2015; Jat *et al*., 2016 and Mohanty *et al*., 2016). Therefore, the adoption of precision nutrient management in maize is expected to pay a rich dividend in India for enhancing crop yield and soil health in future. However, such tools of optical sensor-based N management have been evaluated and standardized in rice (Bijay-Singh *et al*., 2015) and wheat (Bijay-Singh *et al*., 2011) but negligible information is available in maize. Keeping this in view, the available tools like SPAD, SSNM and STCR have been tested with newly developed NDVI algorithms for maize in our study for precision nutrient management.

Materials and methods

A field experiment was conducted at the research farm of ICAR–Indian Agricultural Research Institute, New Delhi, India during *kharif* season of 2016. The different treatments of nutrient application at different growth stages of maize crop *viz*., Control (T_1), RDF (1/3+1/3+/ 1/3 N splitting at basal, knee-high and tasseling) (T_2), STCR (1/3 + 1/3 + /1/3 N splitting at basal, knee-high and tasseling) (T_3), Nutrient expert (1/3 + 1/3 + 1/3 N splitting at basal, knee-high and tasseling) (T_4), 33 per cent basal N + Green Seeker based N at knee-high & tasseling stage (T_5), 60 per cent basal N + Green Seeker based N at knee-high (T_6), 70 per cent basal N + Green Seeker based N at knee-high (T_7), 60 per cent basal N + Green Seeker based N at tasseling stage (T_8), 70 per cent basal N + Green Seeker based N at tasseling stage (T_9), 30 per cent Basal N + 30 per cent at 25 DAS + Green Seeker based N at tasseling stage (T_{10}) and 35 per cent Basal N + 35 per cent at 25 DAS + Green Seeker based N at tasseling stage (T_{11}). The experiment was laid out in a randomized complete block design (RCBD) with three replications comprising the 11 test treatments with a nitrogen-rich strip. The soil was sandy loam low in organic carbon and available nitrogen and phosphorus and medium in available potassium with a slightly alkaline pH of 7.6.

The growth parameters including, plant height, leaf area index (LAI), dry matter accumulation, SPAD and Normalized difference vegetation index (NDVI) were recorded in maize with standard procedure. The yield attributes were also recorded at harvest of the maize. The plant barrenness percentage in each experimental unit was calculated by using the formula given below:

$$\text{Bareness (\%)} = \frac{\text{Plants / plot} - \text{Cobs / plot}}{\text{Plants / plot}} \times 100$$

After harvesting, all the cobs from each plot were sun-dried and after removing the cob sheath, shelling was done using a hand maize sheller. The moisture percentage in the grain was adjusted to 15 per cent to obtain grain yield.

The data recorded for different parameters were analyzed with the help of the analysis of variance (ANOVA) technique for randomized complete block design using SAS 9.3 software (SAS Institute, Cary, NC). The least significant difference test was used to decipher the effect of treatments at a 5 per cent level of significance (*P*=0.05). The Least significant difference (LSD) values for different pair-wise comparisons amongst the treatment effect were computed. Correlation analysis was performed using ProcCORR in the SAS 9.3 software.

Results and discussion

Growth attributes

The highest plant height was recorded with T_3 (STCR) at all growth stages at 30, 60 and 90 DAS (70.44, 191.7 and 197.3 cm) and the lowest with control (Table 1). However, the highest leaf area was recorded under T_8, which was at par with STCR and the other GS based nitrogen management in T_7 to T_{11}. The highest leaf area index (LAI) was recorded at 60 DAS across treatments that might be because at the later stage of the maize crop (90 DAS) the leaves dry up while the number of leaves at the initial stage (30 DAS) are lower. The highest dry matter accumulation (DMA) was also recorded at 90 DAS across all treatments, which could be attributed to the maximum biomass accumulated at the later stage of the maize crop as the leaves dry up but in general, leaves do not detach from the plant. Hence, more DMA was recorded at later growth stages compared to initial growth stages in the crop in contrast to leaf area, which was highest at 60 DAS. Amongst nitrogen management practices, the highest DMA was recorded with T_3 and the lowest was recorded with control at all stages. As the soils of most of the maize growing areas in India are inherently low in soil organic matter and nitrogen is the major limiting plant nutrient, with nitrogen (N) availability being routinely supplemented through the application of fertilizers (Prasad, 2011). As N is the key element in the chlorophyll of the plant and its concentration/supply to the plant have a direct correlation with the photosynthetic area of the plant. The timely supply of N adjusted to crop demand might lead to optimum N nutrition to the crop, which might have enhanced photosynthetic areas in precision nutrient management (PNM) practices and enhanced plant height and DMA in the maize crop. The continuous supply of N to the crop leads to better photosynthesis, which increases the roots and shoots growth in the crop. Efficient nutrient management programmes supply plant nutrients in adequate quantities to sustain maximum crop productivity and profitability while minimizing the environmental impacts of nutrient use (Jat *et al.*, 2013).

The better nutrition made more functional photosynthesis areas that in turn increased the crop growth rate (CGR) in all these treatments. We observed less deviation in the SPAD reading over the period in comparison to normalized difference vegetation index (NDVI), which shows that NDVI is better than SPAD values in maize (Figure 1). At a later stage, NDVI decreases drastically which is not the case with SPAD values as this measure

Table 1. Effect of precision nitrogen management practices on the plant population, plant height, leaf area index, dry matter accumulation and NDVI of *kharif* maize

Treatment	Plant height (cm)	LAI	Dry matter accumulation (g/plant)	Normalized difference vegetation index (NDVI)		
	90 DAS	90 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1	113.7^{d}	1.89^{c}	91.9^{d}	0.51^{d}	0.52^{d}	0.24^{d}
T_2	185.9^{ab}	2.57^{ab}	165.7^{b}	0.54^{cd}	0.65^{bc}	0.27^{bcd}
T_3	197.3^{a}	2.60^{ab}	201.6^{a}	0.62^{a}	0.72^{a}	0.37^{a}
T_4	179.6^{abc}	2.41^{ab}	132.5^{c}	0.59^{bc}	0.62^{c}	0.27^{bcd}
T_5	168.7^{bc}	2.76^{a}	169.5^{b}	0.60^{bc}	0.66^{abc}	0.26^{cd}
T_6	166.6^{c}	2.45^{ab}	161.9^{b}	0.50^{d}	0.62^{c}	0.27^{bcd}
T_7	191.7^{a}	2.41^{ab}	169.4^{b}	0.55^{bcd}	0.68^{ab}	0.27^{bcd}
T_8	197.2^{a}	2.70^{a}	194.8^{a}	0.61^{ab}	0.68^{ab}	0.30^{b}
T_9	196.0^{a}	2.61^{a}	193.0^{a}	0.60^{bc}	0.67^{abc}	0.29^{bc}
T_{10}	179.3^{abc}	2.13^{bc}	173.6^{b}	0.54^{cd}	0.67^{abc}	0.28^{bc}
T_{11}	184.0^{abc}	2.49^{ab}	175.1^{b}	0.54^{cd}	0.66^{bc}	0.26^{bcd}
p-Value	<.0001	0.0469	<.0001	0.0017	0.0002	<.0001

Note: T_1: Control, T_2: RDF, T_3: STCR, T_4: NE-SSNM, T_5: 33% RDN + GS-KH + GS-T, T_6: 60% RDN + GS-KH, T_7: 70% RDN + GS-KH, T_8: 60% RDN + GS-T, T_9: 70% RDN + GS-T, T_{10}: 30% RDN + 30% RDN at 25 DAS + GS-T and T_{11}: 35% RDN + 35% RDN at 25 DAS + GS-T. [Means followed by a similar lowercase letter within a column are not significantly different according to least significant difference test (P=0.05)].

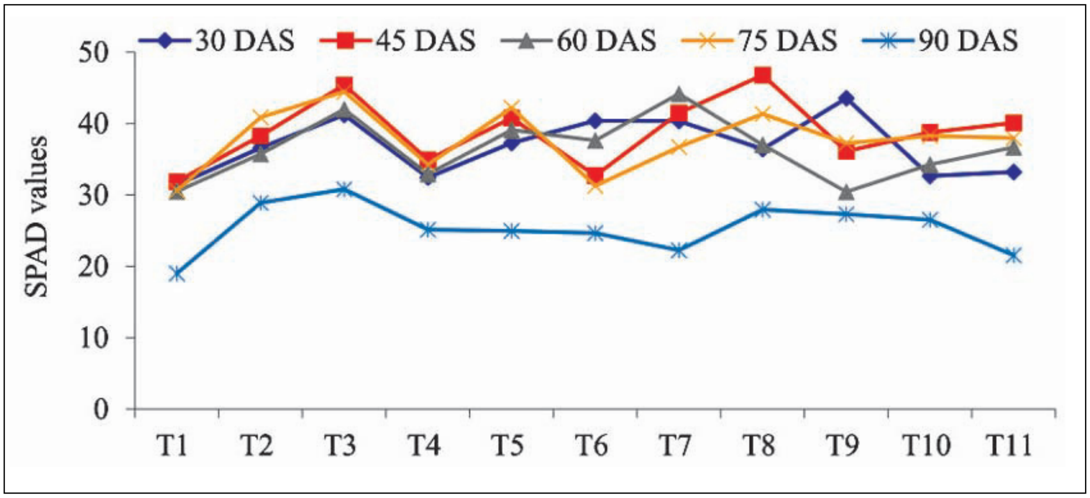

Figure 1. Effect of precision nitrogen management practices on SPAD values of *kharif* maize at different crop stages

Note: T_1: Control, T_2: RDF, T_3: STCR, T_4: NE-SSNM, T_5: 33% RDN + GS-KH + GS-T, T_6: 60% RDN + GS-KH, T_7: 70% RDN + GS-KH, T_8: 60% RDN + GS-T, T_9: 70% RDN + GS-T, T_{10}: 30% RDN + 30% RDN at 25 DAS + GS-T and T_{11}: 35% RDN + 35% RDN at 25 DAS + GS-T.

the health of the leaves not the overall vigour of the crop. Hence, SPAD did not take into account overall crop health. A positive and significant correlation between the NDVI values at 30, 60 DAS and all the growth parameters were observed in *kharif* maize, which indicates that the NDVI could be used as the best predictor for maize health (Table 1). The enhanced availability of N in the soil leads to increased N uptake that in turn leads to increased values of NDVI and SPAD as these values directly correlate with the N in leaves. Singh *et al*. (2013) found that the greenness of wheat leaves at the maximum tillering stage was found to be a function of N applied at planting. Similar findings of better nutrition (STCR/GS) leading to enhanced NDVI and SPAD values in wheat have been reported by Mohanty *et al*. (2016). Precision nutrition (NE-SSNM) linked enhancement in maize growth rate also reported by Ghosh (2015) and Kumar *et al.* (2014) in the same agro-ecologies.

Crop growth rate and relative growth rate

The highest crop growth rate (CGR) was recorded at 0–30 and 60–90 DAS in STCR, while at 30–60 DAS it was with T5 (33 per cent basal + Green Seeker guided) (Table 2). However, the relative growth rate (RGR) at 0–30 DAS was highest in STCR but at 60–90 DAS was with GS guided application (T_8 to T_{11}). In all the cases, the CGR and RGR were lowest in control treatments where no nitrogen was applied (Table 2).

Yield attributes in maize

Significantly, higher number of cobs were recorded in all nitrogen applied treatments over control, while the highest plant barrenness (11.55 per cent) was registered in control plots (Table 3). The cob girth was statistically similar in all the treatments but the cob length increased significantly with different precision nitrogen management practices and was highest in STCR that was statistically at par with RDF and GS guided T_7, T_8 and T_9 treatments. The enhanced nutrient availability, which gave higher crop growth parameters and translated into producing more cobs. This subsequently enhanced cobs/ha along with enhancement in cob length but no differences were observed for cob girth and grain rows/cob. As cob girth and grain rows/cob are more genetically driven parameters of the crop that requires higher management practices to get significantly influenced (Saif-ul-malook *et al.*, 2014). The enhancement in crop growth parameters could be attributed to increased leaf area, plant height and dry matter accumulation in maize, which gave significantly higher cob parameters due to enhanced photosynthetic areas for more resource utilization.

Enhancement in these cob parameters linked with better nutrition/NE-SSNM in maize as reported by Kalpana and Krishnarajan (2002); Kumar *et al.* (2014) and Ghosh (2015). The highest grains/row and grains/cob were registered with GS guided T_9 which was statistically similar to T_3 and other PNM except for T_{11} and T_6 in the

Table 2. Effect of precision nitrogen management practices on crop growth rate and relative growth rate of *kharif* maize

Treatment	Crop growth rate (g/plant/day)			Relative growth rate (mg/g/day)		
	0–30 DAS	30–60 DAS	60–90 DAS	0–30 DAS	30–60 DAS	60–90 DAS
T_1	0.71^{e}	0.82^{d}	1.53^{d}	44.32^{e}	9.47	10.04^{c}
T_2	0.92^{cd}	1.17^{abc}	3.43^{b}	47.91^{d}	11.9	14.14^{ab}
T_3	1.18^{a}	1.30^{ab}	4.24^{a}	51.59^{a}	10.74	14.48^{ab}
T_4	0.94^{cd}	0.87^{cd}	2.61^{c}	48.34^{cd}	11.05	12.91^{ab}
T_5	0.91^{d}	1.36^{a}	3.38^{b}	47.84^{d}	13.21	13.23^{ab}
T_6	1.01^{bcd}	1.16^{abcd}	3.22^{bc}	49.24^{bcd}	11.11	13.27^{ab}
T_7	1.11^{ab}	1.31^{ab}	3.23^{bc}	50.75^{ab}	11.26	12.29^{bc}
T_8	1.01^{bcd}	1.27^{ab}	4.21^{a}	49.41^{bcd}	11.75	15.14^{a}
T_9	1.06^{abc}	1.25^{ab}	4.13^{a}	50.00^{abc}	11.29	14.88^{a}
T_{10}	0.94^{cd}	1.07^{abcd}	3.78^{ab}	48.28^{cd}	11.04	15.30^{a}
T_{11}	1.01^{bcd}	1.00^{bcd}	3.83^{ab}	49.39^{bcd}	9.93	15.45^{a}
p value	0.0002	0.045	<.0001	<.0001	0.5352	0.0088

Note: T_1: Control, T_2: RDF, T_3: STCR, T_4: NE-SSNM, T_5: 33% RDN + GS-KH + GS-T, T_6: 60% RDN + GS-KH, T_7: 70% RDN + GS-KH, T_8: 60% RDN + GS-T, T_9: 70% RDN + GS-T, T_{10}: 30% RDN + 30% RDN at 25 DAS + GS-T and T_{11}: 35% RDN + 35% RDN at 25 DAS + GS-T. [Means followed by a similar lowercase letter within a column are not significantly different according to the least significant difference test (p=0.05)].

case of grains/cob and with all other treatments except T_1, T_6, T_8 and T_{11} for grains/row. The increase in growth and cob parameters led to a better source-sink relationship, which might enhance the grains/cob and grain weight/cob. A similar finding of enhancement in grain attributes in ZT maize was also reported in earlier studies (Kumar *et al.*, 2014; Ghosh, 2015).

Grain yield

The grain yield of maize increased significantly with the application of STCR based nutrition that was on par with T_2, T_8 and T_9 (Table 3). This shows the GS guided N application develops a better source-sink relationship as this synchronises the N supply with crop demand. The increase with STCR was 122.7, 6.3 and 14.3, 13.8, 31.2, 15.0, 4.7, 2.9, 12.0 and 14.1 per cent higher over the T_1, T_2 and T_4 to T_{11}, respectively. However, in comparison to control, the yield in all fertilization treatments was almost more than double in most of the cases that warrant the necessity of efficient nitrogen management in maize. The progressive growth and yield attributes in maize led to a better source-sink relationship in maize that in turn gave higher grain yield of maize due to enhanced mineral N at various crop growth stages found in this study (data not presented). The yield attributes improvement led to increased yield in particular treatment further supported by a significant positive correlation found in our study (Table 4). Moreover, the crop yield is a function of the yield attributes and their efficiency in particular treatment. The blanket recommendations based on the fixed-time application of fertilizer N doses at specified growth stages do not consider the dynamic soil nutrient supply and crop nutrient requirements and lead to the untimely and inefficient application of fertilizer nutrients (Biradar *et al.*, 2012). Therefore, crop need-based fertilizer management in maize can help in improving recovery efficiency and reducing losses of nutrients.

The significant and positive correlation among various crop growth parameters in our study confirms that the photosynthetic area enhancement has a direct relation with other growth parameters. The enhancement in leaf area leads to more photosynthesis that in turn increased the DMA, CGR and RGR under STCR and GS based N application treatments over control and other practices (Table 4). Similar findings of the PNM linked enhancement in crop growth parameters of maize were reported by Kumar *et al.* (2014) and Ghosh (2015). The significant correlation between the growth parameters and cob parameters observed in this study supports our hypothesis of growth lead to enhanced cob parameters. The barrenness in maize significantly reduced due to precision N fertilization as this is the main nutrient responsible for crop growth by way of its direct involvement in

Table 3. Effect of precision nitrogen management practices on yield attributes and yield of *kharif* maize

Treatment	Cobs ('000/ha)	Barrenness (%)	Cob length (cm)	Cob girth (cm)	Grains per row	Grains per cob	1000-grains weight (g)	Grain yield (t/ha)
T_1	58.97^{b}	11.55^{a}	12.67^{d}	11.80	21.11^{d}	267.4^{d}	221.7	2.51^{e}
T_2	71.53^{a}	1.50^{ef}	15.73^{abc}	12.90	27.22^{a}	355.6^{abc}	249.3	5.26^{abc}
T_3	71.08^{a}	0.69^{f}	17.64^{a}	12.76	26.89^{ab}	367.0^{a}	243.3	5.59^{a}
T_4	72.60^{a}	2.36^{cde}	13.03^{d}	12.01	25.89^{abc}	339.1^{abc}	231.7	4.89^{c}
T_5	71.19^{a}	2.04^{de}	15.53^{bc}	12.92	25.78^{abc}	346.8^{abc}	234.7	4.91^{c}
T_6	70.14^{a}	2.95^{cd}	12.79^{d}	12.08	23.68^{bcd}	325.2^{bc}	242.0	4.26^{d}
T_7	70.51^{a}	3.31^{bc}	16.40^{abc}	13.20	27.11a	356.1^{abc}	243.0	4.86^{c}
T_8	71.22^{a}	2.37^{cde}	17.00^{ab}	12.78	25.73^{abc}	360.3^{ab}	234.7	5.34^{abc}
T_9	69.81^{a}	4.27^{b}	16.69^{ab}	12.96	27.33^{a}	379.6^{a}	232.0	5.43^{ab}
T_{10}	71.88^{a}	2.82^{cd}	14.53^{cd}	12.32	27.00^{ab}	360.0^{ab}	238.3	4.99^{bc}
T_{11}	72.63^{a}	2.12^{de}	15.46^{bc}	12.44	23.11^{cd}	318.7^{c}	253.3	4.90^{c}
p-Value	<.0001	<.0001	0.0001	0.1308	0.0117	0.0012	0.0762	<.0001

Note: T_1: Control, T_2: RDF, T_3: STCR, T_4: NE-SSNM, T_5: 33% RDN + GS-KH + GS-T, T_6: 60% RDN + GS-KH, T_7: 70% RDN + GS-KH, T_8: 60% RDN + GS-T, T_9: 70% RDN + GS-T, T_{10}: 30% RDN + 30% RDN at 25 DAS + GS-T and T_{11}: 35% RDN + 35% RDN at 25 DAS + GS-T. [Means followed by a similar lowercase letter within a column are not significantly different according to the least significant difference test (P=0.05)].

Table 4. Correlation matrix among the different yield attributes and yield of *kharif* maize

Parameter	Cobs/ha	Cob length	Cob girth	Grain per row	Grains per cob	Grain weight per cob	Grain yield	1000-grains weight
Cobs/ha	-							
Cob length	0.267							
Cob girth	0.302	0.698***						
Grain/row	0.421*	0.463**	0.468**					
Grains/cob	0.514**	0.550***	0.623***	0.899***				
Grain weight/cob	0.557***	0.532**	0.671***	0.797***	0.860***			
Grain yield	0.788***	0.522**	0.573***	0.688***	0.809***	0.859***		
1000-grains weight	0.439*	0.272	0.417*	0.308	0.298	0.740***	0.570***	
Harvest index	0.690***	0.224	0.360*	0.560***	0.684***	0.705***	0.769***	0.463**

The *, ** or *** indicates significance at 5, 1 and 0.1% probability.

photosynthesis as a constituent of chlorophyll and its significant positive interactions with other nutrients utilization. Moreover, the hybrid maize responses to N fertilization also enhanced and under no fertilization the barrenness could be much higher and sometimes in low fertility soil, it could not reproduce. Thus, it was concluded that application of 33 per cent basal N + GS guided N or 60–70 per cent basal N + GS guided N at tasseling or 30–35% basal N + 30–35 per cent N at knee high + GS guided at tasseling stage could be a better choice for enhancing growth, yield attributes and yield in maize production.

References

Biradar, D. P., Aladakatti, Y. R., Shivamurthy, D., Satyanarayana, T. & Majumdar, K. (2012). Managing fertiliser nitrogen to optimise yield and economics of maize-wheat cropping system in Northern Karnataka. *Better Crops-South Asia,* **6**(1): 19–21.

Gosh, A. (2015). Tillage and nutrient management effects on productivity and nutrient use efficiency of maize. An M.Sc. thesis submitted to PG School, IARI, New Delhi.

Jat, H. S., Jat, R.K., Singh, Y., Parihar, C. M., Jat, S. L., Tetarwal, J. P., Sidhu, H. S. & Jat, M. L. (2016). Nitrogen management under conservation agriculture in cereal-based systems. *Indian Journal of Fertilisers,* **12**(4): 76–91.

Jat, M. L., Satyanarayana, T., Majumdar, K., Parihar, C. M., Jat, S. L., Tetarwal, J. P., Jat, R. K. & Saharawat, Y. S. (2013). Fertilizer best management practices for maize systems. *Indian Journal of Fertilisers,* **9**(4): 80–94.

Kalpana. R. & Krishnarajan, J. (2002). Effect of dose and time of potassium application on yield and quality of baby corn. *Agriculture Science Digest,* **22**(1): 59–60.

Kumar, V., Singh, A. K., Jat, S. L., Parihar, C. M., Pooniya, V. & Sharma, S. (2015). Nutrient uptake and fertilizer-use efficiency of maize hybrids under conservation agriculture with nutrient expert based SSNM practices. *Annals of Agricultural Research,* **36**(2): 160–166.

Kumar, V., Singh, A. K., Jat, S. L., Parihar, C. M., Pooniya, V., Sharma, S. & Singh, B. (2014). Influence of site-specific nutrient management on growth and yield of maize (*Zea mays*) under conservation tillage. *Indian Journal of Agronomy,* **59**(4): 657–660.

Mohanty, S. K., Jat, S. L., Parihar, C. M., Singh, A. K., Sharma, S., Saveipune, D., Sandhya & Kuri, B. R. (2016). Precision nitrogen management practices in wheat influences nutrient uptake and their use efficiencies and fertility status of soil under conservation agriculture. *Annals of Agricultural Research,* **37**(3): 282–289.

Pooniya, V., Jat, S. L., Choudhary, A. K., Singh, A. K., Parihar, C. M., Bana, R. S., Swarnalakshmi, K. & Rana, K. S. (2015). Nutrient expert assisted site-specific nutrient management: An alternative precision fertilization technology for maize-wheat cropping system in South-Asian Indo–Gangetic Plains. *Indian Journal of Agricultural Sciences,* **85**(8): 996–1002.

Prasad, R. (2011). Nitrogen and food-grain production. *Indian Journal of Fertilisers,* **7**(12): 66–76.

Prasad, R., Shivay, Y.S. (2019). Fertilizer nitrogen and global warming – A review. *Indian Journal of Agricultural Sciences,* **89**(9): 1,401–1,406.

Saif-ul-malook, Ahsan, M., Ali, Q. & Mumtaz A. 2014. Inheritance of yield related traits in maize (*Zea mays*) under normal and drought conditions. *Nature and Science,* **12**(9): 36–49.

Singh, B., Sharma, R. K., Kaur, J., Jat, M. L., Martin, K. L., Singh, Y., Singh, V., Chandna, P., Choudhary, O. P., Gupta, R. K., Thind, H. S., Singh, J., Uppal, H. S., Khurana, H. S., Kumar, A., Uppal, R. K., Vashistha, M., Raun, W. R. & Gupta, R. K. (2011). Assessment of the nitrogen management strategy using an optical sensor for irrigated wheat. *Agronomy for Sustainable Development,* **31**: 589–603.

Singh, B., Singh, V., Purba, J., Sharma, R. K., Jat, M. L., Singh, Y., Thind, H. S., Gupta, R. K., Chaudhary, O. P., Chandna, P, Khurana, H. S., Kumar, A., Singh, J., Uppal, H. S., Uppal, R. K., Vashistha, M. & Gupta, R. (2015). Site-specific fertilizer nitrogen management in irrigated transplanted rice (*Oryza sativa*) using an optical sensor. *Precision Agriculture,* **16**: 455–475.

Singh, B., Singh, V., Singh, Y., Thind, H. S., Kumar, A., Singh, S., Choudhary, O. P., Gupta, R. K. & Vashistha, M. (2013). Supplementing fertilizer nitrogen application to irrigated wheat at maximum tillering stage using chlorophyll meter and optical sensor. *Agricultural Research,* **2**(1): 81–89.

Yadav, O. P., Prasanna, B. M., Yadava, P., Jat, S. L., Dhillon, B. S., Solanki, I. S. & Sandhu, J. S. (2016). Doubling maize production and productivity of India by 2025– challenges and opportunities. *Indian Journal of Agricultural Sciences,* **86**(4): 427–34.