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Research Paper

Effect of site-specific nutrient management in conservation agriculture-based maize in north-western India

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ABSTRACT

An experiment was conducted during the rainy (*kharif*) season of 2018 and 2019 at New Delhi, to study the effect of tillage, residue and nutrient-management options on yield, profitability and energy budgeting of maize (*Zea mays* L.). Growing maize under permanent raised bed (PRB) showed significantly (P<0.05) higher grain yield (5.98 and 6.01 t/ha), protein content (9.97 and 10.04 %), protein yield (596.8 and 603.8 kg/ha), production efficiency (PE) (55.4 and 55.6 kg/ha/day) and monetary efficiency (ME) (548.7 and 587.5 ₹/ha/day) over conventional till (CT) plot. Increment ingrain yield (7.35 and 7.14 %), protein content (1.60 and 1.50 %), protein yield (8.68 and 8.50), PE (4 and 3.8 kg/ha/day) and ME (59.0 and 62.2 ₹/ha/day) were noticed under residue retained plot over no-residue plot during 2018 and 2019 respectively. Application of nutrient as per nutrient expert + GreenSeeker (NE + GS) resulted in higher grain yield (5.79 and 5.82 t/ha), protein content (9.97 and 10.03 %), protein yield (578.0 and 584.8 kg/ha), PE (53.6 and 53.9 kg/ha/day) and ME (523.6 and 561.5 ₹/ha/day) over NE alone and soil test-based recommendation (STB) options during 2018 and 2019 respectively. Maximum N content in grain and stover was recorded with PRB with residue retention along with nutrient application as NE and GS-based recommendation, while P and K contents in grain and stover did not differ significantly among the treatment combination during 2018 and 2019 respectively. Overall results revealed that growing maize on permanent raised bed along with 3 t/ha residue retention on surface and precision nutrient prescription using nutrient expert® and green seeker optical sensor is a promising option for sustainable higher productivity, quality and profitability of maize in intensively cultivated area of Indo-Gangatic Plains.

Key words: Green Seeker, Nutrient Expert, Permanent raised bed, Precision nutrient management, Residue management

INTRODUCTION

In India, maize is the third most important crop after rice and wheat, and contributes nearly 9% to the national food basket (Dass *et al*., 2014). For a diversifying agricultural production, maize considered as a viable option owing to its wider adaptability in multiple seasons in different ecologies (Satyanarayana *et al*., 2013a). As consequences of this, increased yield significantly increased the nutrient removal by the crop both macro as well as micronutrients (Jat *et al*., 2013). This lower productivity is mainly due to abiotic stresses like rainfed cultivation, poor soil fertility and biotic stresses like pest and disease problems. Under the farmer's field condition, the imbalanced use of nutrients due to more application of N and P fertilizers and neglecting potassium fertilizers cause poor growth and productivity of maize crop. K is a major nutrient element involved in increasing resistance to drought as well as biotic stresses. Attention should also be given to close the yield gap between potential yield and average farmers yield (Lobell *et al*., 2009). The huge yield gap exists due to the mismatch between state recommendation and farmer's practice which not only decreases the yield but also causes nutrient mining in regions like Indo-Gangetic Plains (IGP).

In this perspective, conservation agriculture (CA) has drawn considerable attention of researchers as it has potential to improve resource-use efficiency and productivity (Parihar *et al*., 2016). Under these circumstances, precision nutrient-management strategy as site-specific nutrient management (SSNM) approach may augment crop productivity and sustain the soil health through ensuring an adequate

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supply of the nutrients specific to the crop and soil (Singh *et al.,* 2017). For this, decision-support tools like Nutrient Expert^{TM} which is based on SSNM principle and use of optical sensors like GreenSeeker^{TM} canopy sensor may offer significant opportunity for developing field-specific fertilizer recommendation, improving productivity and profitability of maize (Satyanarayana *et al*., 2013). In the view of above, the present study was undertaken to assess the effect of precision nutrient-management prescription on growth, yield and yield attributes of CA-based maize-production system.

MATERIALS AND METHODS

The field experiment was conducted during the rainy (*kharif*) season of 2018 and 2019 at research farm of ICAR-Indian Agricultural Research Institute, New Delhi. The soil of the experimental site was sandy loam, low in organic carbon (0.30 %) and available N (237.0 kg/ha), medium in available P (17.0 kg/ha) and K (265 kg/ha), and slightly alkaline in reaction (*p*H 8.2). The experiment was laid down in split-split plot design comprised with 2 treatments in main plot, viz. conventional tillage (CT) and permanent raised bed (PRB), 2 in subplot, viz. without residue (-R) and with 3 t/ha residue (+R), and 3 nutrient-management options, i.e. soil test-based recommendation (STB), Nutrient Expert based (NE) and Nutrient Expert based + Green Seeker (NE+GS) in sub-subplots, replicated thrice. The field operations included 1 ploughing followed by 2 cross-harrowing and levelling to ensure proper tilth in CT plots, while for making raised beds or reshaping, the bed planter was used. The fertilizers were applied as per the treatments. A hybrid maize 'PMH 1' was sown which grows up to a height of about 90–240 cm with 1–2 cobs/plant and matures in 115 days. The plant stays green at maturity, resistant to maydis leaf blight and stalk rot. Seed 22 kg @/ha of hybrid maize was sown using seed drill in CT and bed planter in PRB plots at 60 cm × 20 cm spacing. A pre-plant application of paraquat @ 1.00 kg a.i./ha 2 days before sowing, followed by 1 hand-weeding at 20 days after sowing (DAS), for weed management in the experimental area. Chloropyriphos was also applied once in the both seasons with irrigation water to control termite infestation. Total number of irrigations (including pre-sowing) in maize under various treatments were 8, 7, 6, 5 in PRB-R, PRB + R, CT-R and CT + R, respectively. At maturity, maize cobs were harvested by hand-plucking from 4 m × 4 m net plot area, and grains were separated by sheller. The protein content of the grain was determined by multiplying the nitrogen content of the grain with the correction factor (6.25).

Protein yield of the grain was measured by multiplying the average protein content of grain with grain yield/ha and expressed as kg/ha. This gave the total protein yield/ha and as per given formula:

$$\text{Protein yield (kg/ha)} = \text{Protein content in grain} \times \text{grain yield (kg/ha)}$$

The N, P and K contents of straw and grain were measured separately and expressed in percentage and presented in treatment-wise. Production efficiency measures the grain yield obtained when it is distributed over the duration and expressed as the kg/ha/day. It gives how efficiently crop is produced during the crop duration. It was calculated formula as:

$$\text{Production efficiency} = \frac{\text{Grain yield of the crop in (kg/ha)}}{\text{Duration of the crop in days}}$$

Monetary efficiency was calculated by dividing the total net returns with the duration of the crop and expressed as ₹/ha/day. It gives the net returns of the crop which is distributed over a crop growing period. It was calculated as:

$$\text{Monetary efficiency} = \frac{\text{Net returns (₹/ha)}}{\text{Duration of the crop in days}}$$

Energy budgeting

Energy equivalents of all inputs were summed to get an estimate for the total input energy. Operation-wise energy was calculated on the basis of input energy consumed in field preparation, sowing, fertilizer application, irrigation, intercultural operation weeding, plant protection, harvesting and threshing. The source-wise renewable and non-renewable energy under direct and indirect energies of inputs were also calculated, viz. human labour, water, seed, crop residue, diesel, agro-chemicals (pesticides and herbicides), fertilizers and machinery. However, mechanized harvesting and threshing were assumed for energy calculation on hectare basis.

The grain and straw yields of maize crops and their equivalent yields were converted in terms of energy (MJ/ha) using corresponding energy coefficients. The total output energy is the sum of the entire energy equivalent of grain and straw yields (Mittal and Dhawan, 1988). Net energy return is the difference between the total output energy produced and total input energy required.

Energy ratio was calculated as:

$$\text{Energy ratio} = \frac{\text{Output energy (MJ/ha)}}{\text{Input energy (MJ/ha)}}$$

RESULTS AND DISSCUSSION

Effect on grain and protein yield

The grain yield, protein content and protein yield of maize were significantly influenced by different tillage, residue and nutrient-management options (Table 1). The maximum grain yield (5.98 and 6.01 t/ha), protein content (9.97 and 10.04%), protein yield (596.8 and 603.8 kg/ha) during 2018 and 2019, respectively, were obtained with permanent raised-bed (PRB) which was significantly (P<0.05) superior to CT plot during 2018 and 2019, respectively. The higher yield on PRB may be visualized as lower soil bulk density in top (0-15 cm) soil depth which facilitated better initial crop establishment, more root proliferation leading to efficient soil-nutrient utilization (Singh *et al*., 2010) and soil-thermoregulation due to surface-residue retention (Singh *et al*., 2016). Further, furrows between the beds served as means of drainage during peak rainy days which prevented crops from waterlogging and fungal disease infestation.

The highest grain yield (5.85 and 5.88 t/ha), protein content (9.94 and 10.01 %) and protein yield (582.7 and 589.1 kg/ha) under residue retained plots were significantly (*P*<0.05) superior to no-residue plot. Retaining residues on the soil surface increases soil physico-chemical and biological property while decreases day-time soil temperature (Verhulst *et al*., 2010). The residue retention promoted the formation of more stable macro-aggregates and increased the protection of C and N in the micro-aggregates within the macro-aggregates compared to CT (Singh *et al*., 2016). In hot, tropical climates, this effect is beneficial since soil temperature may be too high for optimum plant growth, whereas in cooler climates the effect can be detrimental to plant development. The lower maximum soil temperature and higher minimum soil temperature in the 0–5 cm surface soil layer under minimum tillage with mulch treatments compared to the CT with no-mulch treatment. This created a more favourable environment for root growth (Singh *et al*., 2016).

Application of nutrient as per Nutrient Expert® and GreenSeeker optical sensor had significantly (P<0.05) higher grain yield than NE and STB. Application of nutrient as per NE showed 1.96 and 1.60% higher yield over STB (5.51 and 5.55 t/ha) during both the years. The maximum protein content (9.97 and 10.03%) and protein yield (578.0 and 584.8 t/ha) during 2018 and 2019, respectively, were recorded over other nutrient-management options. Here it is pertinent to mention the STB suggested nutrient application as per soil fertility status only without any consideration of yield target. Since high-yielding maize cultivar 'PMH 1' was grown in this study and nutrient requirement changes with using productivity, goal, STB did not suffice the nutrient requirement of crop. On the other hand, NE supports nutrient application based on 4R. The NE + GS-based nutrient recommendation increases nutrient supply capacity consistently up to peak reproductive phase therefore improve better nutritional supply to crop, increase nutrient-use efficiency and nutrient uptake leading to increase grain yield, protein content and protein yield of maize (Singh *et al*., 2017; Singh *et al.,*2018).

Effect on NPK content in grain and stover in maize

The concentration of nitrogen (N) in maize grain and stover differed significantly due to tillage, residue and nutrient-management options, while PK content in grain and

Table 1. Effect of tillage, residue and nutrient-management practices on yield and quality of maize

Treatment	Grain yield (t/ha)		Protein content (%)		Protein yield (kg/ha)	
	2018	2019	2018	2019	2018	2019
Tillage practices (TP)						
CT	5.29	5.32	9.77	9.83	518.0	524.3
PRB	5.98	6.01	9.97	10.04	596.8	603.8
SEm±	0.08	0.10	0.018	0.018	1.48	0.78
CD (P=0.05)	0.24	0.30	0.113	0.116	9.16	4.85
Residue management (R)						
-R	5.42	5.46	9.80	9.86	532.1	539.0
+R	5.85	5.88	9.94	10.01	582.7	589.1
SEm±	0.07	0.08	0.013	0.013	2.82	2.87
CD (P=0.05)	0.22	0.26	0.051	0.053	11.03	11.21
Nutrient-management options (NM)						
STB	5.51	5.55	9.81	9.87	541.2	548.2
NE	5.61	5.64	9.84	9.90	553.0	559.2
NE + GS	5.79	5.82	9.97	10.03	578.0	584.8
SEm±	0.017	0.020	0.034	0.034	2.25	2.88
CD (P=0.05)	0.050	0.059	0.103	0.105	6.75	8.65

CT, Conventional tillage; PBR, permanent raised bed; - R:, without residue; + R, with residue (3 t/ha); STB, soil test-based recommendation; NE, nutrient expert-based; NE + GS: Nutrient expert based + GreenSeeker based stover did not differ significantly during both the years (Table 2). The PRB was recorded significantly higher concentration of nitrogen in grain and straw during both the years over CT. Similarly, PRB recorded higher concentration of P and K in grain and straw during both the year over CT plot, respectively. The higher C, N, P and K were noticed under permanent raised-bed planting system with residue retention compared to residue removal (Govaerts *et al*., 2007). Permanent bed helps in enhancing the nutrient-use efficiency, as it reduces soil erosion thereby preventing losses of nutrient from the soil. The increase in soil phosphorus is due to non-mixing of the surface soil under minimum tillage (Sharma *et al*., 2014). Concentration of N in grain and stover of maize was influenced significantly due to residue-management practices. However, the maximum N concentration in grain and stover of maize was noticed with residue-retained plot over no-residue, while PK concentration did not differ significantly among residue management options.

Among the nutrient-management options, NE + GS showed significant higher N content in grain and stover than NE and STB alone during both years. No significant difference among the nutrient-management practices with respect to concentration of P and K in grain and stover were recorded in both the years.It may be due to application of nutrient as per nutrient expert and N optimization by using optical sensor Green Seeker as per crop demand. The increase in nutrient uptake in NE + GS was due to adequate amount and real time fertilizer nutrient application over alone NE and STB treatments (Singh *et al.,* 2018).

Effect on production efficiency and monetary efficiency

Different tillage, residue and nutrient-management options significantly influenced the production efficiency (PE) and monetary efficiency (ME) of maize by (Figs. 1 and 2). The maximum PE (55.4 and 55.6 kg/ha/day) and ME (548.7 and 587.5 ₹/ha/day) were obtained with PRB which was significantly (P<0.05) superior to CT plot during 2018 and 2019, respectively. The higher PE (54.2 and 54.4 kg/ha/day) and ME (519.3 and 557.8 ₹/ha/day) were recorded under residue-retained plot, being significantly

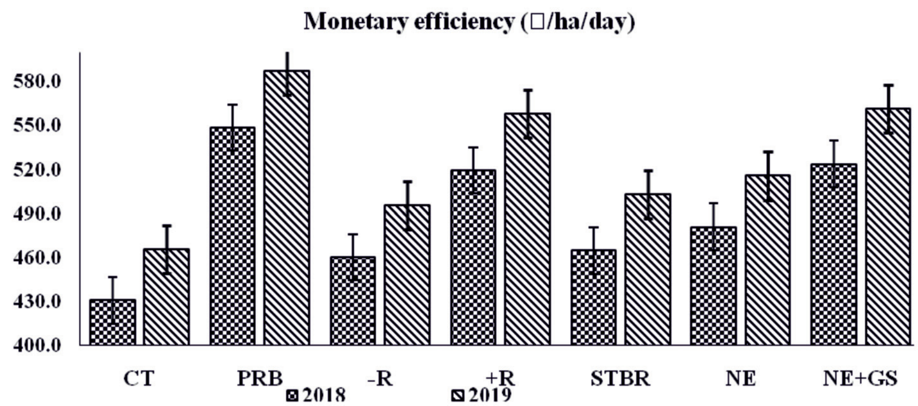

Fig. 2. Effect of tillage, residue and nutrient-management practices on monetary efficiency in maize
CT, Conventional tillage; PBR, permanent raised bed; - R, without residue; + R, with residue (3 t/ha); STB, soil test-based recommendation; NE, nutrient expert–based; and NE + GS, nutrient expert based + GreenSeeker based

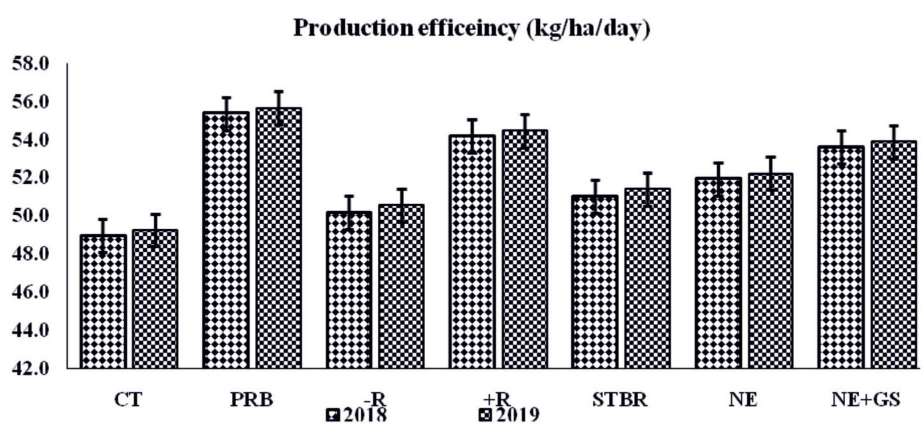

Fig. 1. Effect of tillage, residue and nutrient management practices on production efficiency in maize
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(*P*<0.05) superior to no-residue plot. Our results corroborated the findings of Jat *et al*. (2016) that, CT had significantly lower productivity and profitability per day basis than conservation agriculture (CA)-based practices where residue is retained (PB+). Application of nutrient as per Nutrient Expert® and Green Seeker optical sensor exhibited significantly (*P*<0.05) higher PE (53.6 and 53.9 kg/ha/day) and ME (523.6 and 561.5 ₹/ha/day) than Nutrient Expert-based and soil test-based recommendation. The PE and ME were higher in NE + GS based recommendation than NE and STB alone. It may be owing to better supply of essential plant nutrient as per crop demand and timely application of nutrient leading to improve crop growth and development, increase photosynthesis and translocation of photosynthates from source to sink resulted increased productivity and profitability (Banerjee *et al*., 2014).

Effect on energy budgeting

The total energy input was maximum with CT (48,696 and 48,874 MJ/ha) during 2018 and 2019, respectively, which was 8,102 to 8,526 MJ/ha higher over PRB, respectively, during 2018 and 2019. Significantly higher energy output (189,145 and 189,776), net energy (148,551 and 149,428) and energy ratio (4.66 and 4.70) were obtained with PRB over CT, respectively, during 2018 and 2019 (Table 3). Permanent raised-bed planting reduced the energy requirement than conventional tillage practices owing to saving of energy in land preparation and weeding operations (Jain *et al*., 2007). The higher energy output of maize under PRB might be owing to higher grain and straw yields on permanent beds, residue retention suppressed the residue weeds due to mulching effect thereby reduced herbicide use and lower irrigation water requirement. Gupta *et al*. (2007) also reported significantly higher energy-use efficiency and energy productivity under zero tillage than conventional tillage.The total energy input was maximum with + R (49,009 and 48,994 MJ/ha), which was 8,728 to 8,844 MJ/ha higher over–R respectively, during 2018 and 2019. Significantly higher net energy (137,221 and 137,887 MJ/ha) and energy ratio (4.41 and 4.43) was obtained with –R over + R, respectively, during 2018 and 2019 (Table 3). Choudhary *et al*. (2006) reported that, input-energy consumption was higher with residue application than no-residue application under zero-tillage practice.

Among the nutrient-management options, maximum energy input was required under STB (45,703 and 45,800 MJ/ha), being 1,542 to 1827 MJ/ha and 1,633 to 1,938 MJ/ha higher over NE and NE + GS based-fertilizer, respectively, during both the years. However, significantly higher energy output and net energy were registered with NE + GS and it was significantly higher than NE and STB, respectively, during both the years. The energy ratio was significantly higher under NE+GS over STB but did not differ significant with NE-based nutrient application respectively during both the years of study (Table 3). Inorganic fertilizer accounts for about a third of total energy input and are major indirect energy consumers in crop-production process. Among the various inputs of energy compo-

Table 2. Effect of crop tillage, residue and nutrient-management option on NPK content in maize grain and stover at harvesting

Treatment	N (%)				P (%)				K (%)			
	Grain		Straw		Grain		Straw		Grain		Straw	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Tillage practices (TP)												
CT	1.56	1.57	0.38	0.40	0.30	0.31	0.19	0.20	0.40	0.42	1.46	1.48
PRB	1.59	1.60	0.41	0.43	0.34	0.35	0.21	0.22	0.43	0.44	1.50	1.52
SEm±	0.003	0.003	0.003	0.003	0.008	0.009	0.003	0.004	0.004	0.005	0.029	0.030
CD (P=0.05)	0.016	0.017	0.012	0.014	NS	NS	NS	NS	NS	NS	NS	NS
Residue management (R)												
-R	1.56	1.57	0.39	0.40	0.30	0.32	0.19	0.20	0.41	0.42	1.47	1.48
+R	1.59	1.60	0.41	0.43	0.33	0.34	0.21	0.22	0.43	0.44	1.50	1.51
SEm±	0.002	0.003	0.001	0.002	0.007	0.008	0.006	0.006	0.003	0.003	0.012	0.013
CD (P=0.05)	0.008	0.009	0.004	0.005	NS	NS	NS	NS	NS	NS	NS	NS
Nutrient management options (NM)												
STB	1.57	1.58	0.39	0.41	0.30	0.32	0.19	0.20	0.41	0.42	1.47	1.48
NE	1.57	1.58	0.39	0.41	0.32	0.33	0.20	0.21	0.42	0.43	1.48	1.50
NE + GS	1.59	1.60	0.41	0.43	0.33	0.34	0.21	0.22	0.42	0.44	1.50	1.51
SEm±	0.005	0.006	0.003	0.003	0.010	0.012	0.006	0.007	0.005	0.006	0.024	0.025
CD (P=0.05)	0.016	0.019	0.009	0.010	NS	NS	NS	NS	NS	NS	NS	NS

CT, Conventional tillage; PBR, permanent raised bed; -R, without residue; + R, with residue (3 t/ha); STB, soil test-based recommendation; NE, nutrient expert based and NE + GS, nutrient expert based + GreenSeeker based

Table 3. Effect of crop-establishment methods, residue and nutrient-management options on energy budgeting in maize

Treatment	Energy input (MJ/ha)		Energy output (MJ/ha)		Net energy (MJ/ha)		Energy ratio	
	2018	2019	2019	2019	2018	2019	2018	2019
Tillage practices (TP)								
CT	48,696	48,874	173,766	174,489	125,070	125,615	3.57	3.57
PRB	40,594	40,348	189,145	189,776	148,551	149,428	4.66	4.70
SEm±	-	-	575	582	256	287	0.20	0.25
CD (P=0.05)	-	-	3,553	3,564	1048	1068	0.60	0.70
Residue management (R)								
-R	40,281	40,150	177,502	178,037	137,221	137,887	4.41	4.43
+R	49,009	48,994	185,410	186,228	136,401	137,234	3.78	3.80
SEm±	-	-	576	617	156	187	0.16	0.17
CD (P=0.05)	-	-	2,251	2,412	548	568	0.48	0.54
Nutrient management options (NM)								
STB	45,703	45,800	179,424	179,655	133,721	133,855	3.93	3.92
NE	44,161	43,973	180,595	181,747	136,434	137,774	4.09	4.13
NE+GS	44,070	43,862	184,348	184,996	140,278	141,134	4.18	4.22
SEm±	-	-	562	576	246	284	0.12	0.14
CD (P=0.05)	-	-	1,687	1,694	682	688	0.35	0.38

CT, Conventional tillage; PBR, permanent raised bed; - R, without residue; + R, with residue (3 t/ha); STB, soil test-based recommendation; NE, nutrient expert based and NE + GS, nutrient expert based + GreenSeeker based

nent, fertilizers had highest energy consumption in maize production but also had significant role in improving crop. Therefore, maximum output energy in maize crop are achieved with sufficient nutrient supply.

Based on the findings of the experiment, it can be concluded that permanent raised bed with previous crop-residue retention and precision nutrient prescription using Nutrient Expert® and GreenSeeker was found effective for getting higher grain yield, quality, profitability and energy budgeting in maize.

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