



Effect of nutrient management on yield, economics, water and energy use efficiency of maize (*Zea mays*) under conservation agriculture based maize-wheat (*Triticum aestivum*) system

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ABSTRACT

A field experiment was conducted under long-term conservation agriculture (CA)-based maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-mungbean (MWMb) system at ICAR- IARI, New Delhi (2017–18 and 2018–19) in split-plot design to compute the yields, economic, water and energy use-efficiency. There were 3-tillage treatment in main-plots and 4-nutrient management options in sub-plots with 3-replications. Results of present study showed that the grain yield of maize was 21.1% higher in CA-based permanent bed (PB) than conventional till (CT) plots. Net returns and net benefit cost ratio in PB plots was higher by 46.1 and 55.4% compared to CT, respectively (2-year mean basis). Two year mean basis water use-efficiency (WUE), net energy output and energy use-efficiency (EUE) were higher by 17.0, 26.3 and 12.5% in PB plots than CT. No significant effect of tillage was observed on N, P and K content (grains and stover). However, the total N, P and K uptake in maize grains and stover was higher by 23.6, 24.5 and 22.4% under PB than CT plots, respectively. Among nutrient management options; 2-year mean basis maize grain yield was 31.6 and 29.7% higher in Green Seeker (GS) guided-N and site specific nutrient management (SSNM) plots than farmers fertilizer practice (FFP), respectively. Net returns and BC ratio were also higher by 51.4-53.4% and 41.35-42.6% in GS guided-N and SSNM than FFP plots, respectively. WUE, net energy output and EUE were also significantly higher in GS guided-N treatment than FFP. Total N, P and K uptake were also significantly higher in GS guided-N and SSNM plots compared to FFP.

Keywords: Green Seeker, Nitrogen uptake, Permanent bed, Yield attributes, Zero tillage

Concerns of multiple challenges of sustainability in rice-wheat (RW) system *vis-à-vis* natural resource degradation especially rapidly falling water table and deteriorating soil health in north-west Indo-Gangetic Plains are well documented (Saharawat *et al.* 2010 and Parihar *et al.* 2017). Diversification of rice with maize in the RW system could help in enhancing the crop productivity (Gathala *et al.* 2013), water use-efficiency (Parihar *et al.* 2017), save irrigation water and labour costs (Gathala *et al.* 2013) and may restore/improve the soil health (Parihar *et al.* 2018a). With the development of high yielding maize (*Zea mays* L.) hybrids, which are competitive to rice, maize-wheat (*Triticum aestivum* L.) (MW) system is gaining importance. However, conventional crop management practices entail high production costs (Gathala *et al.* 2013), declined crop

productivity (Jat and Gerard 2014) and are inefficient in input-use (Fahong *et al.* 2004) and excessive tillage often results in sub-soil compaction and loss of soil organic matter (Parihar *et al.* 2016). Under such situations, CA-based ZT and PB should receive high priority to ensure the sustainability of future natural resources with higher productivity at lower cost.

Nutrient management is an important aspect in CA, as it can synergize the benefits from better soil health, enhanced soil moisture and stable thermal regime. Conventionally, blanket fertilizer nutrient prescriptions lead to low nutrient use-efficiency (NUE) and environmental pollution due to field-to-field variability in soil nutrient supply (Bijay-Singh *et al.* 2015). Reduction in soil tillage and provision of optimum crop nutrition can enhance dry matter accumulation and improve plant metabolic activity resulting in better yield, leaf area index (LAI) and crop architecture due to plant × environment interactions (Anjum *et al.* 2014). Improvement in yield, profitability and input use-efficiency due to precision nutrient management compared to FFP have been already reported by many researchers under CT, especially in RW system. But, how it affects the yield, economic profitability, water and energy use-efficiency

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under CA-practices has been evaluated in a few studies that too under short term or medium term CA. Therefore, the present study was carried out to evaluate the performance of maize with respect to crop yield, farm profitability, water and energy use-efficiency under different tillage and nutrient management options in maize-wheat-mungbean (*Vigna radiata* L. Wilczek) system.

MATERIALS AND METHODS

The field experiment was conducted (2017–18 and 2018–19) under long-term CA-based MWMB system at research farm of ICAR-IARI, New Delhi, India (28°38'N, 77°11'E and 228.6 m amsl) to evaluate the effect of CA and nutrient management on yield, economic, water and energy use-efficiency of maize. The mean minimum, maximum temperature, relative humidity and total rainfall during this study period (July- October) was 14-29°C and 10.50-28.5°C, 25-38.5°C and 26-39°C, 46-96% and 40.5-95% and 565 mm and 854 mm in *kharif* 2017 and 2018, respectively. The soil of experimental site was sandy loam in texture with 7.8 pH. The experiment was laid out in the split-plot design with 3-crop establishment techniques (CET); zero tillage with residue retention (ZT+R), permanent bed with residue retention (PB+R) and conventional tillage with residue incorporation (CT+R) in main-plots and 4-nutrient management options; Green Seeker™ based N application (GS guided-N); 100% Ad-hoc; Farmers' Fertilizer Practice (FFP) and Nutrient Expert® decision support tool-based fertilizer application (SSNM) in sub-plots. Treatments were replicated thrice during both the years.

Description of imposed treatments: Maize (PMH-1) was sown at the seed rate of 20 kg/ha at spacing of 67.5 cm × 20 cm in ZT and CT plots. while, one row of maize was planted on top of the bed in PB by keeping plant to plant spacing of 20 cm during 1st fortnight of July and harvested at the end of October (during both the years). The CET and nutrient management options were adopted as described by Parihar *et al.* (2017). In Ad-hoc and FFP plots, nutrient doses were applied as 150:60:40 and 110:30:0

N: P₂O₅: K₂O kg/ha for hybrid maize, respectively. The SSNM recommendations based on the Nutrient Expert® decision support tool were 166.3:36.0:42.8 N: P₂O₅: K₂O kg/ha (2-year average across main and sub-plot treatments) for maize. All crop management practices were adopted as per standard protocols (Parihar *et al.* 2017).

Measurement of growth parameters, yield attributes and yields: Growth parameters, yield attributes, yields and harvest index of maize were computed as per the standard procedure described by Parihar *et al.* (2017).

Nutrient content and uptake: Nitrogen (N), phosphorus (P) and potassium (K) content were estimated by modified *kjeldahl* method (Prasad *et al.* 2006), vanadomolybdo-phosphoric acid yellow color method (Jackson 1973) and flame photometer method (Jackson 1973) respectively. Nutrient uptake was calculated by multiplying nutrient content with maize yields.

Computation of water use-efficiency, energy and economics: The energy coefficients for different parameters, economics and energy and water use-efficiency formula were used as described by Parihar *et al.* (2017, 2018b).

Statistical analysis: Analysis of variance was performed using the GLM procedures of the statistical analysis system (SAS Institute, Cary, NC) for split-plot design. The differences between treatment means were compared using a LSD test at P<0.05 (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Nutrient content and uptake: There was no significant effect of tillage practices on N, P and K content in maize grain and stover. Similarly, the nutrient management options did not influence the N and P content in maize grain and stover (data not presented). However, K content was significantly lower in both grain and stover in FFP, which obviously due to no external fertilizer K application in FFP. The N, P and K uptake in grain and stover was significantly higher under CA-based ZT+R and PB+R plots compared to CT+R, which may be due to higher yield obtained under these plots as nutrient uptake is a function of yield and nutrient content.

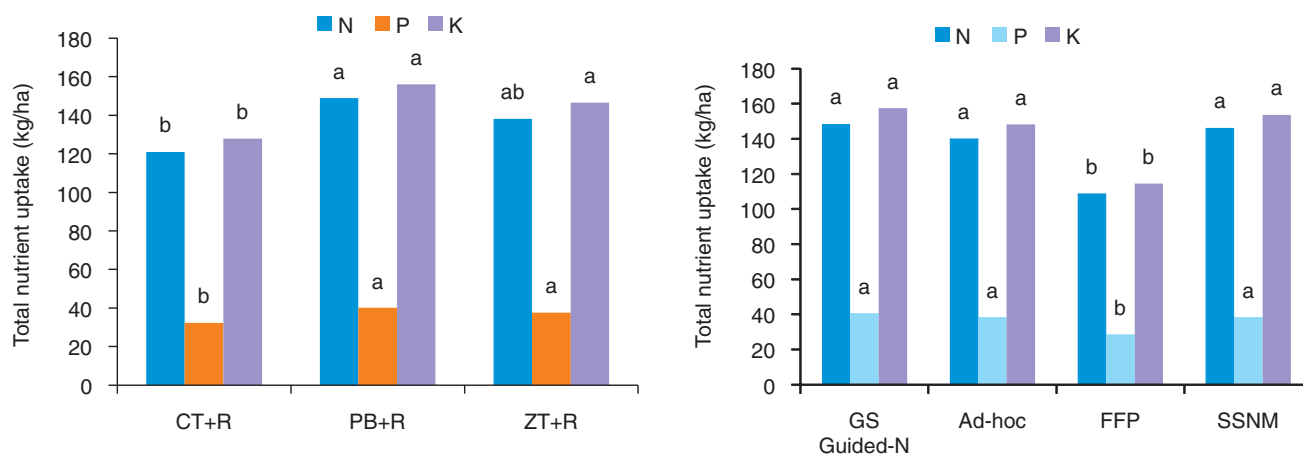


Fig 1 Total N, P and K uptake (grain+ stover) of maize as affected by tillage and nutrient management options under long-term CA-based MWMB system (2-year mean basis). The similar letter used for each nutrient across treatments indicates no significant difference between corresponding treatments.

Table 1 Maize yield attributing characters and nutrient uptake in grain and stover as affected by tillage and nutrient management options under long-term CA-based MWMb system (2-year mean basis).

Treatment	Cob length (cm)	Cob girth (cm)	Grains/row	Grains/cob	100-grain weight (g)	Nutrient uptake (kg/ha)					
						Grain			Stover		
						N	P	K	N	P	K
<i>Tillage and crop establishment techniques</i>											
CT+R	18.4	14.0	33.3	462.8	26.5	81.2	12.4	19.5	39.7	19.8	108.3
PB+R	19.7	14.7	36.3	511.0	28.3	99.3	15.5	23.9	49.6	24.6	132.2
ZT+R	19.4	14.4	34.9	494.8	27.5	92.2	14.6	22.1	45.8	22.9	124.4
SEm±	0.048	0.097	0.468	8.25	0.384	0.80	0.46	0.51	0.76	0.51	3.52
LSD (P=0.05)	0.19	NS	1.84	32.40	NS	3.16	1.81	1.99	2.97	2.00	13.8
<i>Nutrient management options</i>											
GS Guided-N	20.0	14.5	35.6	506.4	27.7	98.8	15.6	24.0	49.6	25.1	133.5
Ad-hoc	19.0	14.5	35.2	499.1	27.6	94.6	15.0	22.7	45.7	23.4	125.6
FFP	18.3	14.1	33.1	458.4	26.8	72.5	11.0	16.8	36.3	17.7	97.7
SSNM	19.5	14.5	35.5	494.3	27.7	97.8	15.1	23.8	48.5	23.5	129.8
SEm±	0.197	0.166	0.391	6.53	0.309	2.70	0.59	0.64	1.00	0.54	2.73
LSD (P=0.05)	0.58	NS	1.16	19.42	NS	8.03	1.76	1.91	2.96	1.59	8.10

Among nutrient management options, significantly higher nutrient uptake was observed under GS guided-N and SSNM compared to FFP. This may be due to optimum supply of nutrients as per crop need (Table 1). Similar trend was observed in total (grains and stover) N, P and K uptake under different tillage and nutrient management options (Fig 1).

Yield attributes: Cob length, grains/row and grains/cob were recorded significantly ($P<0.05$) higher in CA-based PB+R and ZT+R, compared to CT+R plots. PB+R and ZT+R remained statistically at par to each other (Table 1). Among nutrient management options, significantly higher cob length, grains/row and grains/cob were observed with GS guided-N compared to FFP and the values were also statistically at par with the SSNM and Ad-hoc plots. No significant effect of either crop establishment techniques or nutrient management options was observed on cob girth and 100-grain weight (Table 1). There was no significant interaction effect between tillage and nutrient management options.

Yields: Grain yield was significantly ($P<0.05$) affected by tillage and nutrient management options. CA based PB+R and ZT+R treatments recorded 21.1% and 13% higher yield as compared to CT+R, respectively. CA-based PB+R recorded 6.7% higher grain yield compared to ZT+R. Maximum grain yield (2-year mean basis) was observed in CA-based PB+R plots (5694 kg/ha) followed by ZT+R plots (5313 kg/ha). In case of stover yield, similar trend was observed, where significantly ($P<0.05$) higher stover yield was recorded in CA-based PB+R (21.6%) and ZT+R (14.1%) compared to CT. This could be due to compound effect of improved soil physical health, better moisture regimes and improved nutrient use-efficiency under CA-based plots compared to CT (Parihar *et al.* 2017). Among nutrient management options, significantly higher grain yield was recorded under precision nutrient management

and Ad-hoc treatment (31.6%–GS guided-N, 29.7%–SSNM and 29.5%–Ad-hoc) compared to FFP. In case of stover yield, similar trend was observed, where significantly higher stover yield was recorded with GS guided-N (30.72%), SSNM (26.7%) and Ad-hoc (22%) compared to FFP. The results may be attributed to optimum supply of nutrients as per crop demand. There was no significant effect of tillage and nutrient management options on harvest index of maize (Table 2). Tillage and nutrient management options had no significant ($P<0.05$) interaction effect on grain and stover yields of maize.

Water use-efficiency: Tillage practices significantly influenced the total amount of water use and WUE. Significantly higher WUE (10.6 kg/ha-mm) was recorded in CA-based PB+R plots compared to CT+R (9.7 kg/ha-mm) plots. Total water input, i.e. effective rainfall (mm)+irrigation water applied (mm)+soil profile moisture contribution (mm), during maize growing season was mostly contributed by rainfall. The total amount of water used in CA-based PB+R plots was significantly lower (535.9 mm) compared to CT+R (566.7 mm; out of which 426.5 mm water was from effective rainfall and remaining was from irrigation and soil profile contribution). Lesser water use in CA-based PB+R plots might be due to residue mulch retained over soil surface, more concentration time available for water in furrows and less evaporation losses. Findings of the present study are in close conformity with Parihar *et al.* (2017) and Sayed *et al.* (2020). The authors reported that in CA-based PB+R and ZT+R plots, better moisture availability in rhizosphere leads to not only better water absorption but also superior nutrient uptake and microbial activity, better organic matter mineralization and plant growth hormones' release etc, resulted in better crop growth and higher crop biomass production (grain and stover; above and below ground) which, ultimately contributed to higher WUE. The highest

Table 2 Yields, economics, energy and water use-efficiency of maize as affected by tillage and nutrient management options under long-term CA-based MWMb system (2-year mean basis)

Treatment	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)	Net returns ($\times 10^3$ ₹/ha)	Net BC ratio (Net returns/₹ invested)	Water use-efficiency (kg/ha-mm)	Net energy output ($\times 10^3$ MJ/ha)	Energy use-efficiency (output/input ratio)
<i>Tillage and crop establishment techniques</i>								
CT+R	4703	9688	30.1	41.7	1.02	8.30	138.0	3.63
PB+R	5694	11776	30.2	61.0	1.58	10.62	174.3	4.09
ZT+R	5313	11056	30.0	54.8	1.44	9.70	159.3	3.80
SEm \pm	50.0	262.5	0.64	0.61	0.014	0.12	2.79	0.054
LSD (P=0.05)	196.2	1030.4	NS	2.40	0.05	0.45	10.94	0.21
<i>Nutrient management options</i>								
GS Guided-N	5650	11807	29.8	58.9	1.47	10.32	176.5	4.26
Ad-hoc	5415	11077	30.4	54.6	1.37	9.86	160.7	3.80
FFP	4302	9032	29.8	38.4	1.04	7.90	126.1	3.52
SSNM	5578	11443	30.3	58.1	1.49	10.08	165.4	3.77
SEm \pm	132.9	209.6	0.71	2.09	0.054	0.24	2.81	0.052
LSD (P=0.05)	394.7	622.7	NS	6.21	0.16	0.72	8.34	0.15

amount of water used in CT plots (566.7 mm) followed by ZT+R (547.4 mm) and PB+R (535.9 mm) plots, may be due to more evaporation loss, poor crop growth having less leaf area exposing more soil surface to incoming solar radiation and poor root growth with less root density and root hairs for water uptake in CT plots. More evaporation losses in CT plots can also be attributed to intensive tillage operations. Nutrient management options had no significant effect on total water use. However, significantly lower WUE (7.9 kg/ha-mm) was recorded under FFP compared to GS, SSNM and Ad-hoc treatments, which may be due to lower yields owing to imbalanced fertilization and poor crop growth rate (Table 2).

Energetics and Economics: The net energy output, EUE, net returns and net BC ratio (mean of 2-years) of maize were significantly influenced by crop establishment practices (Table 2). The maximum net energy (174.25 thousand MJ/ha), EUE (4.09), net returns (₹ 61000/ha) and net BC ratio (1.58) of maize was recorded under CA-based PB+R plots. CA-based ZT+R and PB+R plots registered 15.4-26.3, 4.5-12.5, 31.2-46.1 and 41.3-55.4% higher net energy output, EUE, net returns and net BC ratio over CT+R, respectively (Table 2). Higher net returns under CA-based PB+R and ZT+R was due to higher yields and lower cost of cultivation compared to CT+R (Parihar *et al.* 2017). The higher energy accumulation under CA was due to better crop growth in terms of better nutrient and moisture availability and higher dry matter accumulation (Parihar *et al.* 2018b).

Nutrient management options significantly influenced the net energy output, energy efficiency, net returns and net BC ratio of maize (Table 2). Significantly higher net energy output, EUE, net returns and net BC ratio was recorded with GS guided-N, SSNM and Ad-hoc compared to FFP. The maximum net energy (176.49 thousand MJ/ha), EUE (4.26)

and net returns (₹ 58900/ha) in maize were recorded with GS guided-N followed by SSNM. Maximum net BC ratio was recorded with SSNM (1.49), which was at par with GS guided-N (1.47). The increased and balanced availability of nutrients result in better crop growth thereby increasing the leaf area for higher incident solar radiation interception and increased photosynthetic rate, which ultimately contributed towards increased output energy and yield thereby increasing the net returns and net BC ratio.

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