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Effect of long-term tillage and diversified crop rotations on nutrient uptake, profitability and energetics of maize (*Zea mays*) in north-western India

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ABSTRACT

The current cereal based systems of South Asia are under threat due to multiple challenges of declining water table, escalating energy and fuel prices, shortages of farm labour, deteriorating soil health with overarching effects of climatic variability making farming uneconomical and unattractive. Conservation agriculture (CA) based management practices together with cropping system optimization have demonstrated to produce more with less while restoring, conserving and sustaining natural resources. In north-western India, maize (*Zea mays* L.) based systems are being advocated as an alternate to rice-based systems to address the issues of resource degradation particularly water table and climate-change-induced variability in rainfall and temperature, etc. However, targeting maize systems without futuristic *best-bet* crop management practices suited to production systems and ecologies, may lead to other problems. Therefore, we attempted to evaluate the performance of maize in *kharif* 2014 under long-term CA-based [permanent bed (PB) and zero tillage (ZT)] practices with conventional tillage (CT) as main-plots and four intensified irrigated maize systems [maize-wheat-mungbean (MWMb), maize-chickpea-*Sesbania* (MCS), maize-mustard-mungbean (MMuMb) and maize-maize-*Sesbania* (MMS)] in sub-plots under an ongoing trial established in 2008. During seventh year of study, higher maize glucose equivalent yield (MGEY) was recorded in ZT (2 942 kg/ha) and PB (2 774 kg/ha) while, the lowest in CT (2 576 kg/ha). Similarly maize glucose equivalent yield under diversified maize-based rotations was invariably higher in MCS and MWMb systems compared to MMuMb and MMS rotations. The results revealed that the maximum total N, P and K uptake (134.7, 40.9 and 156.6 kg/ha) as well as the protein content (8.7%) in maize grain were recorded in ZT, and minimum in CT. However, among the cropping systems plots the *kharif* maize planted in MCS plots registered the highest N, P, K uptake in stover and grain and protein (8.96%) content in grain. Maize net returns and BC ratio were significantly higher under ZT and PB planting compared to CT. Net returns and BC ratio under ZT and PB were higher by 18-29% and 26-38%, compared to CT plots, respectively. The maximum gross output energy (210.1×10^3 MJ/ha), energy efficiency (16.4) and energy intensity (8.50 MJ/₹) were recorded under ZT. Tillage and cropping system interactions significantly influenced maize cob and grain yield in 7th year of experimentation and maximum yield was in ZT-MCS. Overall, our long-term results suggest that adoption of conservation agriculture-based tillage under MCS and MWMb systems can enhance crop productivity, profitability, nutrient uptake and energetics of *kharif* maize in north-western region of India and elsewhere under similar agro-climatic conditions.

Key words: Cropping system, Energy, Maize glucose equivalent yield, Permanent bed, Profitability, Zero tillage

The rice-wheat (RW) cropping sequence of north-west India though provide food security in the country, but the over exploitation of natural resources have led to falling water table (Hobbs and Gupta 2004, Sharma *et al.* 2012) and other issues. These adverse crop production factors more augmented by conventional crop management practices resulted in higher production cost and inefficient use of inputs. Adoption of alternate management practices in RW systems could be the one option for sustainability of existing cropping system, while the diversification of rice with maize (*Zea mays* L.) is another alternative which is more environment friendly (Aulakh and Grant 2008) for

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which the government is also supporting. Under the recent climate change induced variability, maize is on advantageous side with lower water requirement and could be a better alternative to *kharif* (rainy) season rice in this region to enhance the crop as well as system productivity, and sustain soil health and environmental quality (Meelu *et al.*1979).

In past, maize was attempted with conventional management practices as an alternate crop to rice in RW system but it was not successful due to economic reasons. But in recent years with the introduction of single cross hybrid (SCH) technology and development of different maturing (extra early, early, medium and late) high yielding maize hybrids provided genotypic options for crop diversification. However, these hybrids alone are not catching much attention of the growers under traditional crop management practices in north-west India. Maize, an important crop for food and nutritional security in India, is grown in diverse ecologies and seasons covering 9.06 m ha acreage in the country (GoI 2015). Globally, it provides nearly 30% of the food calories to more than 4.5 billion peoples in 94 developing countries, and the demand of maize is expected to double worldwide by 2050 to meet this rising demand and thus higher maize production is need of the hour (Srinivasan *et al.* 2004). During past one decade (2003-04 to 2012-13), in maize area increased by 1.8%, production by 4.9% and productivity by 2.6% per annum which was mainly due to increasing maize demand in India (GoI 2015).

In present scenario due to over exploitation of natural resources (soil and water) and to offset the production cost and environmental footprints, the conservation agriculture (CA) based crop production technologies are gaining attention in this region to explore maximum yield potential of these new SCH in maize (Ladha *et al.* 2009, Jat *et al.* 2009, Saharawat *et al.* 2012). The CA based crop management practices found to be effective for increasing crop productivity (Jat *et al.* 2013, Das *et al.* 2014, Parihar *et al.* 2016), profitability (Parihar *et al.* 2016) and energy-use efficiency (Parihar *et al.* 2011). Furthermore, the intensive traditional tillage practices led to reduction in soil organic matter because of more oxidation and breakdown of organic carbon and ultimately degrade soil properties (Biamah *et al.* 2000, Gathala *et al.* 2011). Published experimental results across the globe have shown increased productivity and soil quality, mainly through SOM build-up (Ladha *et al.* 2009, Bhattacharyya *et al.* 2013) and higher SOC content under zero-tilled compared to conventionally tilled soils (West and Post 2002, Alvarez 2005, Parihar *et al.* 2016a).

Adoption of CA principles with 'Best–Bet' crop management practices would be helpful in expansion of maize area in north-west India. So as, to generate new information for sustainable intensification of maize systems in north-west India, a long-term study was initiated at ICAR-IIMR research farm, New Delhi to evaluate the impacts of tillage and crop establishment practices on the performance of four intensified maize based cropping systems. In this paper, we summarized the results of *kharif* maize performance with respect to glucose equivalent yield, nutrient uptake, profitability and energetics planted after six years under CA practices in diversified maize based cropping systems.

MATERIALS AND METHODS

A long-term field experiment established in the monsoon season of 2008 under a set of tillage and crop establishment practices in four diversified maize-based cropping systems at the research farm (28°40' N, 77°12' E and 228.6 m elevation) of the ICAR-IIMR, Pusa Campus, New Delhi, India. The climate of the area is semi-arid, with a mean annual rainfall of 650 mm (70-80% of which received during July-September) with the mean annual evaporation of 850 mm. Daily metrological parameters during cropping season were recorded at ICAR-IARI metrological observatory. The mean minimum, maximum temperature and total rainfall during this study period of *kharif* 2014 (July-October) was 23.7°C, 33.3°C and 451 mm, respectively. The soil of experimental site (before *kharif* 2008) was sandy loam in texture with 7.8 pH, Walkley–Black C (0.42%), EC (0.32 dS/m), $KMnO_4$ oxidizable N (158.4 kg/ha), 0.5 M $NaHCO_3$ extractable P (11.6 kg/ha) and 1 N NH_4 OAC extractable K (248.4 kg/ha) and diethylene triamine penta acetic acid (DTPA), extractable Zn (1.6 mg/kg), Fe (6.7 mg/kg) and Cu (1.3 mg/kg).

The experiment was conducted with three main-plot treatments consisting of tillage and crop establishment practices [zero tillage (ZT), permanent bed (PB) and conventional tillage (CT)] and four sub-plot treatments of intensified maize based systems [maize-wheat-mungbean (MWMb), maize-chickpea-*Sesbania* (MCS), maize-mustard-mungbean (MMuMb) and maize-maize-*Sesbania* (MMS)]. The experiment was designed in split-plot arrangements with three replications at fixed site. The each experimental unit consisted of 16.5 m × 4.0 m plots.

The field was deep ploughed by chisel plough to break the hard pan below the plough layer and laser leveled before start of the experiment. The CT planting involved one ploughing each with cultivator, disc harrow and rotavator, however in ZT, no ploughing was done. But in case of PB reshaping of beds were done at the end of every cropping cycle in one-go simultaneously with seed and fertilizer placement using raised bed multi-crop planter. Residues of every preceding crop/s was/were retained/incorporated as such on the soil. In the first year of experimentation (before start of experiment in *kharif* 2008) an equal quantity of mungbean and *Sesbania* residue (1.5 Mg/ha) was retained/incorporated in all plots. The maize cv HQPM-1, a quality protein maize hybrid was sown with a seed rate of 20 kg/ha during first fortnight of July in 2014 with a row spacing of 67 cm and plant to plant distance at 25 cm. The sowing of maize was done by zero–till multi-crop bed planter in PB, zero-till multi-crop planter in ZT and multi-crop planter in CT. The maize crop was harvested at the end of October 2014.

A common dose of nutrients amounting 150 kg N + 60 kg P_2O_5 + 40 kg K_2O + 25 kg $ZnSO_4$/ ha were applied in all treatments during first year of study (2008). The 1/3rd N and whole P_2O_5, K_2O and $ZnSO_4$ was applied as basal, while remaining 2/3rd N was top dressed as urea in two equal splits at V_5 and V_T vegetative growth phases. At the time of top dressing, fertilizer was broadcasted and care was taken so that the fertilizers were mainly applied on targeted crop rows only. In view of best weed management, herbicide gylphosate was sprayed @ 1.0 L a.i./ ha in all the ZT and PB plots about two days before sowing of crop. However, in case of CT plots Atrazine @ 1.0 kg a.i./ha was applied as pre-emergence (PE) to control weeds. In addition to chemical weed management, one hand weeding was also done in all the CT plots at 30–40 days after sowing. While no weeding was done in ZT and PB plots except uprooting of hardy perennial weeds during initial two years.

At maturity, the crop was harvested manually at a height of about 40 cm above ground during experimentation. The maize cobs were harvested from 10.72 m^2 area and threshed by maize plot sheller to estimate the grain yield. Grain moisture was determined using a grain moisture meter. The grain yield of maize was adjusted at 14% moisture content. The yield maize crop was adjusted for differences in energy costs of the synthesis of the maize, as glucose equivalent yield. The glucose maize equivalent yield was calculated based on bioenergetics (amount of substrate required for growth of seeds). The glucose equivalent yield (GEY) was calculated based on energy requirement to produce one kg of cereal as described by Penning *et al.* (1979).

Plant samples collected at harvest were dried in hot air oven at 60°C for 6 hours. These oven-dried samples of plants as well as the air-dried sample of grain were ground to pass through 40 mesh sieve in a Macro-Wiley Mill and used for chemical analysis. In grain and stover nitrogen (N) was determined by modified Kjeldahl method, phosphorus (P) content by vanadomolybdophosphoric acid yellow colour method and potassium (K) content in grain and stover was determined by flame photometer (Prasad *et al.* 2006). The uptake was calculated by using the following:

Nutrient uptake (kg/ha) in grain/stover = [% Nutrient in grain/stover × grain/stover yield (kg/ha)]

Total uptake of N/P/K (kg/ha) = N/P/K uptake in grain + N/P/K uptake in stover

Crude protein content in maize grain was calculated by multiplying N concentration with a coefficient factor 6.25. This factor is based on the nitrogen content (16.0%) of the maize protein.

Energy efficiency and energy intensity were calculated by using the following formulae as suggested by Mittal and Dhawan (1988) and Singh *et al.* (1997).

$$\text{Energy efficiency} = \frac{\text{Energy output (MJ/ha)}}{\text{Energy input (MJ/ha)}}$$

$$\text{Energy intensity (in economic terms MJ/₹)} = \frac{\text{Energy output (MJ/ha)}}{\text{Cost of cultivation (₹/ha)}}$$

The primary data collected on various inputs and management practices for *kharif* maize crop were used for computation of energy consumption, and it's various ratios. The energy output from the economic and by-product yield was also estimated. The loss of output was very negligible due to natural calamities and pests. Thus, the loss or waste is not included.

The net returns (NR) of each treatment combination were calculated by deducting the total cost (TC) of cultivation from gross returns (GR) of respective treatments and the benefit: cost ratio was calculated by dividing the net returns with total cost of cultivation.

All data recorded were analyzed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez 1984) for split-plot design using SAS 9.3 software (SAS Institute, Cary, NC). The least significant test was used to decipher the main and interaction effects of treatments at 5% level of significance ($P<0.05$).

RESULTS AND DISCUSSION

Yields

The tillage and cropping system effects on maize glucose equivalent yield (MGEY) were significant during the experimentation (Table 1). The data of MGEY showed that MGEY was significantly ($P<0.05$) higher by 14.2 and 7.7% in ZT and PB compared to CT planting, respectively. However, maize planted on PB yielded at par with ZT flat. The MGEY of *kharif* sown maize also differed significantly ($P<0.05$) under intensified cropping systems. Maximum MGEY (2 937 kg/ha) was recorded under MCS system followed by MWMb (2 799 kg/ha) as compared to other cropping systems (MMuMb and MMS) (Table 1). After six cropping cycles at fixed plots the tillage and crop rotations had significant ($P<0.05$) interaction effect on grain and cob yields of maize (Fig 1).

However, the tillage and crop rotations interaction effect on yield attributes was not found significant (data not presented). The highest maize grain and cob yield was found in ZT-MCS, which was followed by ZT-MWMb and lowest was in CT-MMuMb. ZT-MCS and ZT-MWMb plots registered 35-38.7% and 26.6-40.3% higher maize grain and cob yields compared to CT-MMuMb plots, respectively. Our findings of higher yields under ZT and PB of maize are in agreement with Jat *et al.* (2013), Gathala *et al.* (2013) and Parihar *et al.* (2016). In contrast to our findings, Lahmar (2010) summarized that the crop yields were lower with CA compared to CT practices in fertile soils of Europe. The higher yield of maize in ZT/PB systems could be due to the compound effects of additional nutrients (Blanco-Canqui and Lal 2009, Kaschuk *et al.* 2010) reduce competition for resources due to lesser weed population (Ozpinar 2006, Chauhan *et al.* 2007), improved soil physical health (Jat *et al.* 2013) and better water regimes (Govaerts *et al.* 2009) with higher resource-use efficiency, aeration and efficient nutrient use (Unger and Jones 1998) over CT. In addition to all these factors, structure of soil affects

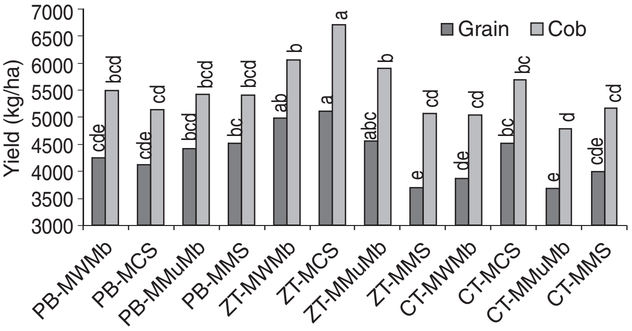

Fig 1 Interaction effect of long term tillage and diversified cropping systems on cob and grain yields of *kharif* maize (2014) grown after six cropping cycles. *The bars followed by a different letter are significantly different (at $P < 0.05$) according to least significant difference test.

crop yield through a complex of root based mechanisms which affect the biomass production (Passioura 2002) and root growth found better under CA compared to CT due to lesser compaction (Blanco-Canqui *et al.* 2006). The higher maize yield with MCS compared to rest (MWMb, MMuMb, MMS) cropping systems might be due to inclusion of two legumes (one winter and another in summer) compared to only summer legume in other cropping systems (Congreves *et al.* 2015). The inclusion of summer legumes in preceding season might have improved the soil fertility; particularly N availability thereby improved growth and yields of *kharif* maize.

Nutrient uptake

The N, P, K uptake by grain and stover and protein content in maize grain were significantly influenced due to different tillage practices and cropping systems (Table 1 and Fig 2). The maximum total (grain + stover) N, P and K uptake of 134.7, 40.9 and 156.6 kg/ha, respectively, as well as the protein content (8.7%) in maize grains was recorded in ZT plots, while minimum uptake of all these nutrients and protein content was recorded with CT planting during *kharif* 2014. The higher uptake of these nutrients in maize under CA practices might be due to better root development, which enhanced nutrient density in maize crop due to increased forage area for nutrient extraction. Beside this, the retention of mungbean/sesbania residue recycled the nutrients in soil layers and ultimately enhances nutrient availability in crop root zone which might lead to more nutrient uptake. In addition to this, the chelating forms of nutrients due to higher SOM content in ZT helps in retaining more nutrients with lesser losses of soil applied fertilizer nutrients. The higher concentration of these nutrients along with higher yield ultimately leads to higher uptake as uptake is derived by multiplication of nutrient concentration in grain and stover with respective yields. Moreover, these nutrients (NPK) are synergistic to each other in nature and uptake of one enhances the uptake of other as well. The higher concentration of N in grain resulted enhancement in protein content of maize as this is one of the essential part of amino acid and basic unit for protein synthesis. The similar finding of higher NPK uptake under ZT were also reported by Wani *et al.* (1995), Alam *et al.* (2014) and Naresh *et al.* (2014).

Data pertaining to N, P, K uptake by maize grain and stover and protein content in grain were reflected that diversified maize based cropping systems significantly influenced these parameters. The maximum N, P, K uptake by grain and stover and protein content was observed when *kharif* maize was sown in MCS sequence plots as

Table 1 Effect of long term tillage practices and diversified cropping systems on glucose equivalent yield, quality and nutrient uptake in maize after six cropping cycles

Treatment	Glucose equivalent yield (kg/ha)	Protein content (%)	N uptake (kg/ha)		P uptake (kg/ha)		K uptake (kg/ha)	
			Grain	Stover	Grain	Stover	Grain	Stover
Permanent bed	2774	8.55	65.0	59.4	15.0	22.3	20.2	124.9
Zero tillage flat	2942	8.69	70.2	64.5	15.1	25.8	20.7	135.9
Conventional tillage	2576	8.31	56.8	53.7	13.5	19.6	17.0	112.8
SEm±	68.2	0.066	1.68	1.49	0.32	0.94	0.42	2.80
CD (*P=0.05*)	267.7	0.26	6.59	5.84	1.26	3.71	1.66	10.97
p-value	0.0470	0.035	0.012	0.017	0.041	0.024	0.007	0.011
MWMb	2799	8.48	65.0	59.9	15.0	23.4	19.5	137.2
MCS	2937	8.96	72.2	62.3	15.1	24.5	21.5	126.8
MMuMb	2708	8.22	60.1	59.3	13.8	22.1	18.0	113.0
MMS	2612	8.40	58.6	55.2	14.3	20.2	18.4	121.2
SEm±	66.5	0.056	1.54	2.50	0.26	0.64	0.47	3.67
CD (*P=0.05*)	197.6	0.17	4.59	7.41	0.76	1.91	1.39	10.89
p-value	0.0184	<0.0001	<0.0001	0.266	0.005	0.001	0.0002	0.002
p-value interaction	0.0008	0.204	0.001	0.002	0.287	<0.0001	0.230	0.030

MWMb: Maize-wheat-mungbean, MCS: Maize-chickpea-*Sesbaina*, MMuMb: Maize-mustard-mungbean, MMS: Maize-maize-*Sesbania*.

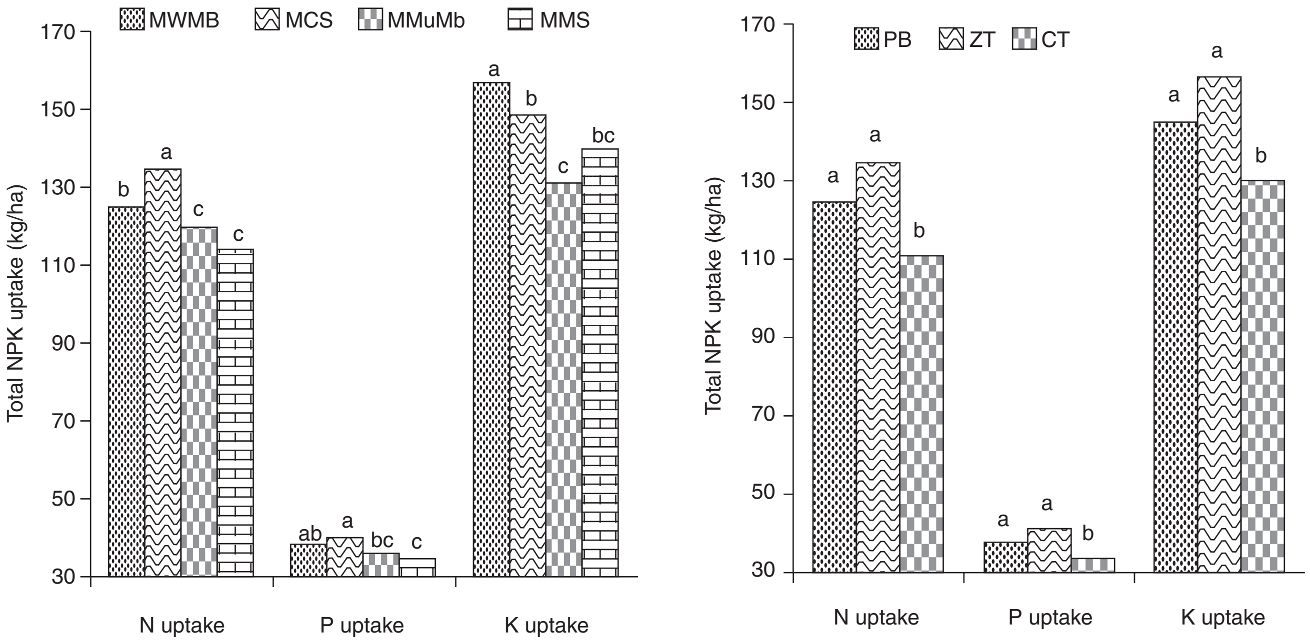

Fig 2 Effect of long term tillage practices and diversified cropping systems on total NPK uptake in maize grown after six cropping cycles. *The bars followed by a different letter are significantly different (at $P < 0.05$) according to least significant difference test.

compared to other cropping sequences. The planting of *kharif* maize in MCS sequence registered 15.4, 12.9 and 5.9% increase in total N, P and K uptake (grain + stover) over to MMS, respectively. Similarly, the maximum protein (8.96%) content was also recorded in maize grain under MCS plots after six cropping cycles at fixed site. The inclusion of deep rooted legumes with shallow rooted cereals in the systems might help in extraction of sub-surface nutrients to surface through leaf and twig fall. This in turn increases the nutrient availability in surface soil layers where maximum concentrations of maize roots existed. The higher nutrient availability might help in higher uptake of N, P and K. The enhancement of NPK uptake due to inclusion of legumes has been earlier reported by Parihar (2014) and Aziz *et al.* (2015).

Energetics and economics

After the six years of study, total energy output, energy efficiency, energy intensity, net returns and BC ratio of *kharif* maize were significantly influenced due to different crop establishment practices (Table 2). The maximum gross energy (210.1 thousand MJ/ha), energy efficiency (16.4), energy intensity (8.50 MJ/₹), net returns (45 681₹/ha) and BC ratio (1.85) of *kharif* maize were recorded under ZT planting. ZT and PB planting registered 7.5-13.4, 34.2-40.2, 14.7-20.9, 18-29.2 and 26-38.1% higher gross energy, energy efficiency, energy intensity, net returns and BC ratio over to CT planting, respectively. However, all these energy and economics indices are statistically similar in both the CA-based tillage practices (ZT and PB). Adoption of ZT and PB in maize leads to higher energy efficiencies and monetary returns in our study then that of CT planting. In this study, the higher energy efficiencies in maize production with CA might be due to two reasons; either due to less energy consumption in CA compared to CT or due to higher production (which leads to more energy output per unit of

Table 2 Effect of long term tillage practices and diversified cropping systems on energy indicators and economics of maize after six cropping cycles.

Treatment	Gross output energy ($\times 10^3$ MJ/ha)	Energy efficiency (output/ input ratio)	Energy intensity (MJ/ ha-₹)	Net returns (₹/ha)	BC ratio
Tillage practices					
Permanent bed	199.2	15.7	8.06	41744	1.69
Zero tillage flat	210.1	16.4	8.50	45681	1.85
Conventional tillage	185.3	11.7	7.03	35363	1.34
SEm±	2.55	0.20	0.103	1275.5	0.05
CD (*p=0.05*)	10.00	0.78	0.40	5007.3	0.205
p-value	0.006	0.0002	0.001	0.012	0.005
Cropping systems					
MWMb	203.3	15.0	8.08	41952	1.67
MCS	209.2	15.3	8.29	44973	1.78
MMuMb	194.0	14.2	7.69	39576	1.57
MMS	186.2	13.8	7.40	37216	1.48
SEm±	4.22	0.31	0.167	1459.6	0.06
CD (*p=0.05*)	12.54	0.92	0.50	4336.8	0.204
p-value	0.006	0.009	0.007	0.009	0.011
p-value interaction	0.0001	<.0001	<.0001	0.001	0.001

MWMb: Maize-wheat-mungbean, MCS: Maize-chickpea-*Sesbaina*, MMuMb: Maize-mustard-mungbean, MMS: Maize-maize-*Sesbania.*

energy used) or both. However, the higher net returns might be due to lower cost of cultivation and higher yields under CA compared to CT practices. The energy accumulation capacity was higher in CA due to better crop growth environment in terms of higher nutrient availability, better root growth and modulation of climatic conditions with better water retention. The enhanced energy efficiency in CA practices compared to CT was also reported by Ram *et al.* (2010) and Parihar *et al.* (2011).

Diversified maize based cropping systems also significantly influenced the gross energy output, energy efficiency, energy intensity, net returns and BC ratio of *kharif* maize. The highest net energy (209.2 thousand MJ/ha), energy efficiency (15.3), energy intensity (8.29 MJ/₹), net returns (44 973 ₹/ha) and BC ratio (1.78) were recorded when the crop was planting in MCS system plots compared to other diversified cropping sequences. However, after six cropping cycles at fixed site the lowest values of all these energy and economic indices of *kharif* maize were observed in MMS system. The energy efficient maize under MCS system was primarily due to higher yields compared to other systems which enhnced output per unit of input energy used. Thus, the higher productivity is one of the option for enhancing energy efficiencies of maize systems which was also reported by Parihar *et al.* (2011).

Our study demonstrated that CA-based (ZT and PB) management practices under the multiple challenges (yield plateau, water and labour shortages, high energy costs, diminishing farm profits and climatic change induced variability) provides an alternative for sustainable intensification of maize systems with legume inclusion for achieving the higher yields, energy use efficiency and profitability from *kharif* maize in north-western India. However, layering of precision water and nutrient management solutions with CA need further research to realize more benefits and reduce environmental foot prints in maize based systems.

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