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Effect of different tillage and residue management practices on crop and water productivity and economics in maize (*Zea mays*) based rotations

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ABSTRACT

In recent years, increasing water and labor scarcity & production cost, decreasing farm profitability and climate-change-induced variability are major challenges faced by the farmers of Indo-Gangetic Plains (IGP) in South Asia. Conservation agriculture (CA) based best-bet crop management practices may increase crop productivity, profitability and conserve the natural resources. In a 2-year (2012-2014) study, we assessed the effects of six combinations of tillage and crop establishment (TCE) and residue management options on crop & water productivity, profitability and soil thermal and moisture regimes in maize (*Zea mays*)-wheat (*Triticum aestivum* L.) (MW) and maize-chickpea (*Cicer arietinum* L.) (MC) rotations in Western IGP of India. The treatments consisted of both crops sown on permanent raised beds with residue (PB+R) and without residue (PB-R); zero tilled flat with residue (ZT+R) and without residue (ZT-R) and conventional tilled flat with residue (CT+R) and without residue (CT-R). Overall, 2-year mean maize, wheat and chickpea grain/seed yield was found to be 17.0-23.2, 20.8-24.8 and 22-31.7% higher under CA-based PB+R/ZT+R than CT-R, but it was 5.3-10.9, 4.9-8.4 and 13.8-22.8% higher than CT+R, respectively. The yield of maize, wheat and chickpea was significantly ($P<0.05$) higher in CA-based PB+R and ZT+R systems compared to CT-R right from first year onwards. The MW and MC, 2-year mean system productivity (based on maize equivalent yield- MEY) was higher by 21.1-21.9 and 18.7-27.5% in CA-based systems (PB+R & ZT+R) than in the CT-R, respectively. CA-based PB+R and ZT+R practices reduced the total system water use in MW and MC rotations by 75-112 mm and 55-90 mm and resulted enhanced system water productivity (WP) compared to CT-R system. Irrespective of crop rotations and TCE practices residue management treatments enhances the soil moisture (in the range of 14.5 to 30.4% during winter and monsoon seasons) and also moderates the soil temperatures. Economic profit for MW and MC rotations was always significantly ($P<0.05$) higher (168-445 and 215-619 US$/ha/year) in CA-based systems than in CT-R. Findings of our study shows that MW and MC rotations under CA-based system is one of the way for improving crop productivity, WP and farm income with less risk of extreme temperature and moisture stress while sustaining the natural resources in Western IGP of India and other similar agro-ecologies of South Asia.

Key words: Conservation agriculture, Cropping systems, Net returns, Soil moisture Soil temperature

Rice-wheat (RW) system in north-west India, ensuring food security of the country had led to soil degradation and over exploitation of underground water resources (Sharma *et al.* 2012). Furthermore, conventional crop management practices of cereal-based systems entail higher production costs, depletion and/or degradation of natural resources (water, soil, biodiversity, *etc*) across the IGP region (Jat *et al.* 2014). The diversification of RW systems with maize-based systems and alternate soil tillage and crop management practices could enhance the system productivity, sustain soil health and environmental quality (Parihar *et al.* 2016), and save irrigation water and lowers labour cost (Aulakh and Grant 2008). In any cropping system, crop management practices are the key factor for its productivity, efficiency, sustainability and soil health (Parihar *et al.* 2016). Alternate and viable crop production methods may help in addressing the challenges of conventional tillage based cereal production systems. Therefore, the farmers of the region immediately need alternative planting options to reduce their production costs and water-use. Of particular interest is the conversion to conservation agriculture (CA). As cereal based systems with alternate CA-based management practices could help

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in enhancing the system productivity and saving irrigation water, enhancing moisture availability is often referred as climate smart package (Parihar *et al.* 2017).

The CA embodies three major principles–reduced or zero tillage, rational soil cover at all times, and judicious crop rotation. Experimental evidence from various production environments suggests that CA-based management can reduce production costs, stabilized crop yield and improved WP (Bhushan *et al.* 2007). Concurrently maize is rapidly emerging as a favorable option for farmers in India and South Asia. Maize based systems are emerging as profitable rotations in the irrigated region of Trans-Gangetic Plain in India. Maize yields are certainly affected by the soil moisture tillage and residue management practices, which together influence emergence, root development and nutrient availability. Other winter season crops are affected by soil temperature, as soil temperature has role in germination, microbial respiration, nutrient diffusion, root growth and hence overall productivity. Therefore, CA-based management coupled with crop diversification can create favorable soil environment for crop establishment and suitable crop microclimate during other physiological and phenological stages. CA-based alternative tillage and crop establishment methods have been designed and tested in IGP (Jat *et al.* 2013). However, most efforts in western IGP revolved around zero tillage in wheat and on a small scale in legumes in a commodity centric approach and not on a system basis. Hence, the potential benefits of CA-based management have not been realized in most production systems. Moreover, the MW and MC are relatively new and emerging crop rotations, wherein the role of CA-based management has not been studied in western Gangetic Plains. Hence, there exists a large knowledge gap on CA in MW and MC systems.

Considering these facts, the present study was conducted to investigate the impacts of CA technologies (ZT with and without residue retention and PB with and without residue retention) on the crop and water productivity and associated economics of MW and MC cropping systems in the western IGP. The objectives were: (i) to evaluate the impacts of CA on crop yield and above-ground biomass productivity (net primary productivity) under maize-wheat and maize-chickpea systems, (ii) to assess the effects CA practices on water productivity and net returns and (iii) to evaluate the effect of residue management options on soil moisture and temperature. We hypothesized that CA-based PB/ZT with residue retention would result in higher crop and water productivity and net returns compared with farmers' practice (conventional till without residue). In this paper, we discuss effect of six tillage, crop establishment and residue management combinations on crop, system and water productivity and economic profitability and soil moisture and temperature.

MATERIALS AND METHODS

A field experiment was conducted during monsoon and winter seasons of 2012-13 and 2013-14 under six tillage and crop establishment (TCE) and residue management practices under maize-wheat and maize-chickpea crop rotations at the research farm (28°40' N, 77°12' E and 228.6 m elevation) of the Directorate of Maize Research (DMR), New Delhi, India. The rainfall pattern of the experimental site was relatively variable during the two years of study. The rainfall during monsoon season (July–October) was higher (1198.8 mm) in 2013 and it was only 481.8 mm in monsoon season 2012. The rainfall in winter season (November to April) was very low (161.9-176.0 mm) during both the years.

The treatments consisted a set of six TCE and residue management practices, i.e. permanent raised beds with residue (PB+R) and without residue (PB-R); zero tilled flat with residue (ZT+R) and without residue (ZT-R) and conventional tilled flat with residue (CT+R) and without residue (CT-R). In ZT flat, crops were directly drilled using ZT planter with inverted 'T' tynes. While, in raised beds (PB) (with width of the beds; mid-furrow to mid-furrow was 67 cm, with 37cm wide flat tops, and 15 cm furrow depth) planting was done by using raised bed multi-crop planter. The CT flat planting involved one ploughing each with disc harrow followed by spring-tyne cultivator and rotavator.

In the first monsoon season, Quality protein maize hybrid HQPM-1 was sown with 20 kg/ha seed rate and in winter season wheat (cultivar HD 2967) and chickpea (cultivar Pusa 547) crops were sown with 100 and 80 kg/ha seed rate, respectively. Crop based fertilizers doses (N: P_2O_5: K_2O) were applied in different crops @ 150:60:40, 30:40 and 120:60:40 kg/ha for maize, chickpea and wheat, respectively. In all the treatments, 33% N and 100% P_2O_5 and K_2O doses were applied at sowing in maize and wheat. Rest 67% N was applied in 2-equal doses at V_5 and tasseling stages in maize, and at first and third irrigation in wheat. In chickpea, whole of the N + P_2O_5 were applied at the time of seeding. In all the residue management plots, about 30% of preceding crop residues was retained/incorporated and the remaining amounts of residues from these plots and full (above ground) amount of residue from non-residue management plots was removed to use as fodder and other purposes.

The yield data of grain/seed and stover/straw of maize, wheat and chickpea were converted to standard moisture percentage of 14% (maize), 12% (chickpea) and 12% (wheat). To compare the performance of diverse crop rotations, the ultimate criterion was system productivity converted as maize equivalent yield (MEY). Minimum support prices for maize, wheat and chickpea as fixed by government of India were used to convert these crops yield to equivalent yields of maize and then all were summed up to give system productivity in terms of maize yield. Following equation (1) the MEY based on price was calculated.

$$MEYp = \text{Maize yield} + ((WY \times Wp) \text{ or } (CY \times Cp)) / Mp \qquad (1)$$

where, MEYp is the MEY based on price; WY is the wheat yield (Mg/ha); CY is the chickpea yield (Mg/ha); Wp is the wheat price (US$/Mg), Cp is the chickpea MSP (US$/Mg) and Mp is the MSP of maize (US$/Mg).

Soil temperature (2013–2014) was measured by LCD digital water proof thermometers. The sensing range of thermometer was -50^{o}C to $+200^{o}$C with stainless sensor probes. All the thermometers were obliquely placed into 10 cm soil depth. The 10 cm soil depth was chosen because it was slightly below the seed zone depths of all the crops (of about 4-9 cm) and represents maximum rhizosphere activity. Soil temperatures were manually recorded at 8 am and 2 pm every day for whole the year except the rainy days. The monthly mean temperature was calculated by taking daily mean temperatures to reduce the daily fluctuation in soil temperature. Similarly, soil surface (0-10 cm) moisture measurement was done by gravimetric methods. Irrigation water was applied in all the crops based on visual crop symptoms at critical crop growth stages by flood irrigation through open channels. A parshall flume (3´´) was installed in the main open channel under free flow conditions to calculate the amount of irrigation water applied to the crops. The flow rate and the water applied in each plot were computed by using the standard procedure adopted by Savva and Frenken (2002) and Parihar *et al.* (2017). Manual rain gauge installed adjoining to experimental field was used to calculate the amount of rainfall received. Total applied irrigation water and rainfall were summed in order to get total water input in each treatment. The water productivity (kg grains/ha-mm) was computed as ratio of crop yield (kg) to the total water input (irrigation + rainfall) (ha-mm) as described by Bhushan *et al.* (2007).

The economic net returns from combined treatments were computed separately considering the incurred variable cost only. Major input factors for crop production with variable costs involved are, use of energy (human and machinery) for diverse farming practices like residue management, seed bed preparation, sowing, nutrient and insecticide application, water management, harvesting and threshing. The labour cost was calculated with the minimum wage rate as per the Indian Labour Law on person-days basis for a hectare land, by taking into account 8 h to be equal to 1 person-day (Minimum Wages Act 1948). Likewise, a tractor-drawn machine/ implement time (h) necessary to complete a field operation was counted, and expressed as hours per ha. The cost for different operations was computed using time and diesel consumed for each field operation and diesel market price. Every input cost was summed up to work out the total variable cost (TVC) of crop production. The gross returns (GR) were computed by multiplying the economic output (grain/seed and straw/stover yields of each crop) with their individual prices. The net returns (NR) were computed by calculating the difference between GR and total variable cost (TVC) (NR = GR-TVC). The net returns of crop rotations were computed by totaling the net returns from all the component crops grown in a particular cropping system in a year. Indian rupees (INR) were changed into USD by considering the average exchange rate during the study years.

The data were subjected to analysis of variance (ANOVA) using the general linear model procedures of the statistical analysis system (SAS Institute, Cary, NC) for the crop yield, water productivity and economics of maize, wheat, chickpea and cropping system in completely randomized block design. The differences between treatment means were compared using a LSD test at $P < 0.05$ (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Crop and system productivity

The ANOVA showed significant treatment effects of the tillage, crop establishment and residue management practices on 2-year (2012-2014) grain/seed and stover/straw yields of monsoon maize and winter season wheat and chickpea (Table 1). The data of two years showed that grain yield of monsoon season maize was significantly ($P<0.05$) higher by 22.2-24.3, 16.6-17.5 and 10.5-11.7% under CA-based ZT+R, PB+R and CT+R plots compared to conventional tilled without residue (CT-R) plots, respectively. TCE and residue management treatments had significant effect on wheat and chickpea yields. The enhancement in yield of wheat was by 13.7-27.5% (in PB+R and -R), 13.0-22.6% (in ZT+R and -R), and 14.7-15.5% (in CT+R) compared to conventional

Table 1 Crop productivity as affected by different tillage & residue management practices under maize-wheat (MW) and maize-chickpea (MC) rotations in western Indo-Gangetic Plains.

Treatment	Maize grain yield (Mg/ha)		Wheat grain yield (Mg/ha)		Chickpea seed yield (Mg/ha)	
	2012	2013	2012-13	2013-14	2012-13	2013-14
Tillage and residue management practices						
PB+R	4.85^{ab} (11.9^{a})*	5.57^{ab} (12.7^{a})	4.41^{a} (5.71^{a})	4.71^{a} (6.43^{a})	2.01^{ab} (5.17^{ab})	2.24^{ab} (5.99^{ab})
PB-R	4.23^{cd} (11.0^{bc})	5.26^{b} (13.1^{a})	4.11^{a} (5.56^{a})	4.34^{a} (5.77^{bc})	1.83^{bc} (4.86^{bc})	2.07^{bc} (5.63^{b})
ZT+R	5.09^{a} (11.9^{a})	5.89^{a} (13.1^{a})	4.3^{a} (5.62^{a})	4.53^{a} (6.16^{ab})	2.13^{a} (5.45^{a})	2.46^{a} (6.32^{a})
ZT-R	4.55b^{cd} (10.6^{cd})	5.46^{ab} (13.3^{a})	4.08^{a} (5.55^{a})	4.21^{ab} (5.67^{bc})	1.88^{bc} (5.07^{abc})	2.17^{bc} (5.73^{b})
CT+R	4.65^{abc} (10.6^{cd})	5.24^{b} (12.8^{a})	4.17^{a} (5.74^{a})	4.24^{ab} (5.73^{bc})	1.80^{bc} (4.58^{c})	1.93^{cd} (5.53^{b})
CT-R	4.16^{d} (10.0^{d})	4.74^{c} (11.6^{b})	3.61^{b} (4.53^{b})	3.7^{b} (5.33^{c})	1.74^{c} (4.53^{c})	1.75^{d} (5.42^{b})

*Data in parentheses indicates the stover/straw yield of respective crop. Means followed by a similar lowercase letter within a column are not significantly different (at $P < 0.05$) according to Least significant difference test.

tilled without residue (CT-R) plots, respectively. However, chickpea seed yield was significantly ($P<0.05$) higher by 15.5-28.5 and 22.5-41.0% under CA-based PB+R and ZT+R plots compared to CT-R plots, respectively. Our experiment result are in consistent with Parihar *et al.* (2016), who reported greater yield under CA-based practices compared to CT. Considering the enhancement in yield it can be concluded that maize and chickpea performed better under ZT, while wheat performed better under PB as compared to CT. Performance of chickpea was well enhanced with residue retention in ZT. The impact of TCE and residue management options on the stove yield of maize, wheat and chickpea was inconsistent during both the years of experimentation (Table 1). Earlier findings also had similar conclusion, higher crop yields under CA compared to CT in diversified cereal base cropping systems (Jat *et al.* 2013). The higher yield of maize in CA systems could be due to the combined effects of added nutrients (Blanco-Canqui and Lal 2009, Kaschuk *et al.* 2010), smaller weed population (Ozpinar 2006), enhanced soil physical health (Jat *et al.* 2013) and superior moisture regimes (Govaerts *et al.* 2009) and better nutrient use efficiency over CT (Unger and Jones 1998).

The TCE and residue management practices had significant ($P<0.05$) effect on system productivity (maize equivalent yield, MEY) of MW and MC rotations for both the years of study (except MW, MEY in 1st year) (Table 2). Mean MEY of MW and MC was highest (10.37 and 11.12 Mg/ha) in ZT+R followed by (10.30 and 10.38 Mg/ha) in PB+R and was lowest in CT-R (8.50 and 8.73 Mg/ha), respectively (Table 2). These findings are in close conformity with those reported by many workers (Jat *et al.* 2013, Parihar *et al.* 2016). They reported higher system productivity in CA-based PB compared to CT in maize-wheat production system. CA-based PB and ZT practices with residue retention (PB+R /ZT+R) in MW and MC rotations increased the MEY by 1.04±0.47 & 0.69±0.19 and 0.83±0.48 & 1.10±0.28 Mg/ha/year compared to PB and ZT without residue retention (PB-R/ZT-R). The increase in system productivity (MEY) under full CA-based PB+R and ZT+R of MW and MC rotations was 1.80±0.34 & 1.65±0.29 and 1.86±0.21 & 2.40±0.28 Mg/ha/year over to absolute conventional system (CT-R), respectively (Table 3). In our study, eliminating tillage (CA-based PB and ZT with residue retention compared to CT with residue incorporation) in MW and MC rotations had significant yield benefit (0.72±0.22 and 1.23±0.19 Mg/ha/year) on MEY (Table 3). The findings of increased system productivity under CA with residue retention in our study are in agreement with the results obtained by other researchers (Jat *et al.* 2014) that might be due to better soil structure, aeration and thermal and moisture regimes (Kumar and Ladha 2011, Parihar *et al.* 2016a).

System water-use and water productivity

In both the years of study, the total water input (irrigation + rainfall) for all the TCE methods and residue management practices in MW and MC rotations was significantly lower by 6.8-10.6 & 5.5-9.6%, 4.5-7.0 & 3.4-5.9% and 1.1-2.0 & 1.2-2.2% in PB+R, ZT+R and CT+R plots compared to CT-R plots, respectively (Table 2). Irrespective of TCE methods variation among the residue management practices for total water input was significant in both the crop rotations (MW/MC) and years of study, PB+R plots received least amount of water (848-1641 ha-mm), while

Table 2 System crop (Maize equivalent yield-MEY) and water productivity of maize-wheat (MW) and maize-chickpea (MC) rotations as affected by different tillage and residue management practices in western Indo-Gangetic Plains

Treatment	MW system productivity (Mg/ha)		MC system productivity (Mg/ha)		Total MW system water input (irrigation + rainfall) ha mm		Total MC system water input (irrigation + rainfall) ha mm		MW system water productivity (kg/ha-mm)		MC system water productivity (kg/ha-mm)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Tillage and residue management practices												
PB+R	10.05	10.56^{a}	9.84^{b}	10.92^{b}	888^{f}	1641^{f}	848^{f}	1551^{f}	11.3^{a}	6.4^{a}	11.6^{a}	7.0^{ab}
PB-R	8.63	9.90^{a}	9.22^{c}	10.15^{bc}	908^{e}	1661^{e}	868^{e}	1571^{e}	9.5^{cd}	6.0^{ab}	10.6^{b}	6.5^{cd}
ZT+R	10.09	10.65^{a}	10.45^{a}	11.79^{a}	923^{d}	1681^{d}	883^{d}	1586^{d}	10.9^{ab}	6.3^{a}	11.8^{a}	7.4^{a}
ZT-R	9.24	9.83^{a}	9.34^{bc}	10.72^{b}	938^{c}	1696^{c}	893^{c}	1596^{c}	9.9^{bc}	5.8^{ab}	10.5^{b}	6.7^{bc}
CT+R	9.47	9.76^{ab}	9.22^{c}	9.82^{c}	973^{b}	1741^{b}	918^{b}	1621^{b}	9.7^{bcd}	5.6^{bc}	10.0^{b}	6.1^{d}
CT-R	8.38	8.63^{b}	8.53^{d}	8.93^{d}	993^{a}	1761^{a}	938^{a}	1641^{a}	8.4^{d}	4.9^{c}	9.1^{c}	5.4^{e}
Monsoon season Rainfall (mm)	481.8	1198.8										
Winter season Rainfall (mm)	176.0	161.9										
Total Rainfall (mm)	657.8	1360.7										

Means followed by a similar lowercase letter within a column are not significantly different (at $P < 0.05$) according to Least significant difference test.

Table 3 Grain yield and net return advantage under different components of conservation agriculture (CA) in maize, wheat, chickpea and their respective crop rotations. Values (mean±S.E.) are of two years comparison.

Particulars	Treatment comparison	Additional yield (Mg/ha)					Additional net income (USD/ha)				
		Maize	Wheat	Chick-pea	MW system	MC system	Maize	Wheat	Chick-pea	MW system	MC system
Advantage of residue retention on double PB system	[(PB+R)-(PB-R)]	0.93 ± 0.38	0.34 ± 0.09	0.18 ± 0.10	1.04 ± 0.47	0.69 ± 0.19	159 ± 84.7	33 ± 22.2	45 ± 40.6	156 ± 100.6	81 ± 39.6
Advantage of residue retention on double ZT system	[(ZT+R)-(ZT-R)]	0.96 ± 0.29	0.27 ± 0.18	0.27 ± 0.08	0.83 ± 0.48	1.10 ± 0.28	175 ± 48.6	16 ± 12.3	99 ± 44.5	113 ± 102.9	177 ± 67.3
Double PB (+R) system as compared to absolute conventional system	[(PB+R)-(CT-R)]	1.52 ± 0.40	0.91 ± 0.11	0.38 ± 0.05	1.80 ± 0.34	1.65 ± 0.29	377 ± 93.9	218 ± 25.6	179 ± 29.9	419 ± 78.8	356 ± 63.8
Double ZT (+R) system as compared to absolute conventional system	[(ZT+R)-(CT-R)]	2.07 ± 0.11	0.57 ± 0.12	0.41 ± 0.16	1.86 ± 0.21	2.40 ± 0.28	501 ± 18.5	162 ± 29.4	224 ± 75.4	431 ± 45.7	526 ± 64.3
Advantage of tillage elimination	[(PB+R/ ZT+R)-(CT+R)]	0.40 ± 0.11	0.28 ± 0.19	0.34 ± 0.04	0.72 ± 0.22	1.23 ± 0.19	125 ± 22.7	103 ± 44.0	215 ± 20.1	227 ± 49.8	342 ± 43.1

SE=Standard error.

CT-R plots received maximum (938-1761 ha-mm). During the high rainfall year (2013-14) both partial and full CA-based plots of MW rotation resulted statistically similar water productivity (5.8-6.4 kg/ha-mm), while during low rainfall year (2012-13) significantly higher (by 6.7%) water productivity was observed in full CA-based PB+R plots compared to partial CA-based PB-R plots (Table 2). However in MC rotation irrespective of rainfall events, residue retention plots of PB and ZT had significantly higher water productivity (by 6.7-8.9 & 8.7-10.7%) as compared to without residue retention plots of PB and ZT plots (Table 2). The CT+R and CT-R plots of MW crop rotations had similar water productivity during both the years, but MC rotation had significantly higher WP in CT+R plots in both the years compared to CT-R. The WP of PB plots was higher due to supply of irrigation water in furrows (Parihar *et al.* 2017). The residue retention on the soil surface in ZT system minimized evaporation losses and hence enhanced soil moisture availability for transpiration (Aggarwal and Goswami 2003). Greater availability of soil moisture in the seed-zone improved crop growth and also augmented water productivity. Our research findings are in consistent with the findings of Jat *et al.* (2013). The higher WP during low rainfall year (2012-13) in our study supports this concept of superior soil moisture regime in CA-based management practices (Thierfelder and Wall 2010).

Economics

The variable cost of production of both the crop rotations was increased with residue retention in all the TCE methods by 9.3-11.5%. However, among the residue retention plots CA-based plots had 5.9-7.0% lower cost of production as compared to CT+R, these savings in cost of production was primarily due to non-requirement of preparatory tillage (Jat *et al.* 2013). The least cost (668-776 US$/ha-yr) was incurred in partial CA-based PB-R and ZT-R plots in both the crop rotations, while the highest cost was imposed by CT+R (792-917 US$/ha-yr). In our study; adoption of full CA or partial CA practices increased the net returns by US$ 168-445 and 215-619/ha-yr over CT-R in MW and MC systems, respectively. The highest BC ratio was observed in both MW (1.93-2.29) and MC (2.27-2.85) systems during both the years in full or partial CA-based plots (Table 4). In agreement with our findings, increased system productivity and economical profitability of rice–wheat and maize–wheat systems by adopting CA-based-ZT/PB has also been reported by other researchers (Jat *et al.* 2013, Saharawat *et al.* 2010).

Soil thermal and moisture regimes

The monthly mean soil moisture content was varied with the amount of effective rain fall and irrigation water applied (Fig 1). During all the months residue retention plots had higher moisture than residue removed plots. During second year of study the greater differences in soil moisture (>0.75% w/w) between residue retained and residue removed plots was in the monthly order of April >July> September> November>March>August. The maximum variation in soil moisture during April month coincides with harvesting. Variation in July, August and November months may be accounted by sowing and early slow growth of maize, wheat and chickpea, where land is very less covered due to poor canopy development and causes maximum evaporation losses. Residue has more albedo and lower evaporative losses; this may be responsible for larger variation in soil moisture content particularly during the hot summer and early slow growth period of the crops. Variation during September and March may be due to some other unaccounted micro-climatic parameters like wind

Table 4 Economics of maize-wheat and maize-chickpea rotations as affected by different tillage and residue management practices in western Indo-Gangetic Plains

Treatment	Variable cost of cultivation (US$/ha-yr)				Net returns over variable cost (US$/ha-yr)				BC ratio			
	Maize-wheat system		Maize-chickpea system		Maize-wheat system		Maize-chickpea system		Maize-wheat system		Maize-chickpea system	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Tillage and residue management practices												
PB+R	853	812	779	745	1620	1750^{ab}	1625^{b}	1867^{b}	1.90^{a}	2.16^{a}	2.09^{b}	2.51^{b}
PB-R	776	735	701	668	1374	1683^{ab}	1550^{b}	1779^{b}	1.77^{ab}	2.29^{a}	2.21^{ab}	2.66^{ab}
ZT+R	853	812	779	745	1623	1772^{a}	1768^{a}	2064^{a}	1.90^{a}	2.18^{a}	2.27^{a}	2.77^{ab}
ZT-R	776	735	701	668	1500	1669^{ab}	1574^{b}	1904^{ab}	1.93^{a}	2.27^{a}	2.25^{a}	2.85^{a}
CT+R	917	869	830	792	1417	1512^{bc}	1399^{c}	1580^{c}	1.55^{bc}	1.74^{b}	1.69^{c}	1.99^{c}
CT-R	839	792	752	715	1206	1327^{c}	1335^{c}	1445^{c}	1.44^{c}	1.67^{b}	1.77^{c}	2.02^{c}

Means followed by a similar lowercase letter within a column are not significantly different (at $P < 0.05$) according to Least significant difference test.

speed. Residue retention also modulated the soil temperature during all the months of the year (Fig. 2). Annual coefficient of variation (CV) of temperature in residue retained plots was less by~6% than residue removed plots; this indicates more fluctuation of temperature under residue removed plots. During winter months from mid October to March soil temperature in residue retained plots was generally more than residue removed plots, which is beneficial for winter season crops. Dry maize stalk has 20% lower thermal conductivity than soil and has albedo of 0.18 as compared to 0.08 for moist soil (Van-Wijk *et al.* 1959). Maximum temperature differences coincided with maximum (30.4-31.9°C) and minimum (12.7-14.5°C) soil temperature during July and January months, respectively. Similar lower temperature under no till residue retention was also reported by Shen *et al.* (2018), they also found that maize residue has an effect in insulating the soil temperature. A slight greater temperature during winter season and lower temperature during summer season helps to enhance crop performance.

Conclusions

This study with CA-practices such as PB and ZT planting with residue retention under 2-different crop rotations has significant impact on economic benefits and higher crop and water productivity in low rain fall year. Residue retention has significant impact on soil moisture retention and soil thermal regimes. With better soil moisture and temperature, growth, productivity and profitability of maize-wheat/chickpea cropping systems well enhanced. The key messages from the study is: CA-based MW and MC systems appears to be the upcoming cropping systems as well as an important strategy to increase the system productivity and farm profitability on sustainable basis in Western IGP of India. The potential benefits of CA-based management systems are less vulnerability to temperature fluctuation and moisture stress. However, further research on component management practices (genotype choices, precision nutrient management, accounting temporal variability under contrasting management, *etc*) for local adaptation of basic elements of CA-based technologies is critical for large-scale adoption.

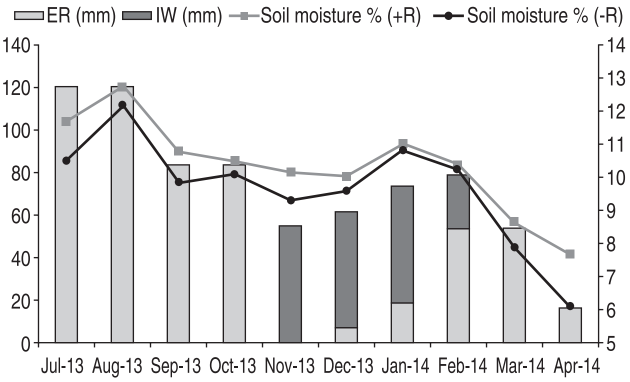

Fig 1 Variation in soil moisture due to residue management [with residue (+R) and without residue (–R)] during 2013-14. ER=Effective rainfall, IW=Irrigation water applied.

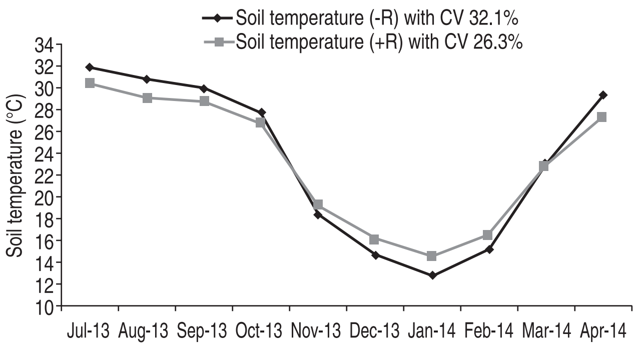

Fig 2 Annual soil temperature variation due to residue management [with residue (+R) and without residue (–R)] during 2013-14. CV = Coefficient of Variance.

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