

Productivity, resource-use efficiency and economics of maize (*Zea mays*)–wheat (*Triticum aestivum*)–greengram (*Vigna radiata*) cropping system under conservation agriculture in irrigated north-western Indo-Gangetic plains

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ABSTRACT

A field experiment was conducted during 2011–12 and 2012–13 in New Delhi, to evaluate conservation agricultural practices on crop productivity, profitability and resource-use efficiency of maize (*Zea mays* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.]–greengram [*Vigna radiata* (L.) Wilczek] cropping system. Four main plots treatments, viz. conventional tillage with flat and raised bed planting (CTF and CTB) and zero tillage with flat and raised bed planting (ZTF and ZTB) were supplemented with 4 subplots treatments, viz. no residue control (CON), wheat residue in maize crop (WR), maize residue in wheat crop (MR) and wheat + maize residue (WMR) in both maize and wheat crops. Each residue was applied at 2.5 t/ha. The experiment was laid out in a split-plot design. Greengram was grown during summer under zero till condition and its residue was retained in all the plots except CON. The results of 2 year pooled data revealed that the system productivity (maize grain-equivalent yield, MGEY) was found comparable among ZTF, ZTB and CTB (13.0–13.2 t MGEY/ha). The ZTF incurred the least cost (₹73.4 thousand/ha), but fetched significantly higher net returns (₹94.1 thousand/ha) and benefit: cost (1.28) in the cropping system. Irrigation water productivity and energy productivity of the system were significantly higher with ZTB. The WMR increased the total cost by 16.5% in comparison to CON, however, showed the highest crop productivity, profitability and water productivity of the system. The WMR showed the least energy productivity. Overall, zero tillage with residue retention throughout crop cycle was more productive, remunerative and irrigation water-use efficient in the maize–wheat–greengram system.

Key words : Conservation agriculture, Economics, Maize–wheat–greengram system, Productivity, Resource-use efficiency

Conventional agricultural system, mainly involves improved crop varieties, higher level of production inputs like fuel for land preparation, synthetic fertilizers, irrigation water and chemicals etc. Such inputs, substantially increased the foodgrain production but at the cost of declined profitability (Saharawat *et al.*, 2012). Maize–wheat is the third most important cropping system grown on about 1.83 million ha in India, and contributes nearly 3%

to the national food basket after rice–wheat and rice–rice system (Sepat *et al.*, 2013). The north-western part of the Indo-Gangetic plains (IGP) is characterized with low rainfall and light texture soil but has well-developed irrigation facilities and farm mechanization. In cereal-based cropping systems, huge volume of crop residues are produced and used as animal feed, thatching homes and domestic fuels. Large portion of unused crop residues are spread on wheat field by combine-harvester which are not suitable to feed the cattle because soil particles are attached with them. Residue application through soil incorporation has been found beneficial to soil health, crop productivity, nutrient-use efficiency. Tillage is the basic and most important requirement of crop production creating environment for plant growth. But, conventional land preparation requires several passes of disc and harrow to incorporate crop residues with aim to create a suitable seed bed. Additional tillage leads to a long turn around period, result-

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ing 2–3 weeks delay in sowing of succeeding crop to avoid N-immobilization (Singh *et al.*, 2004). Further along with more fuel consumption, wearing and tearing of tillage machines increased the cost of production. As such farmers choose to burn the residues in the field for sowing succeeding crops. Burning of residues has drawn the attention of researchers and planners, as this practice has several adverse effects on soil and environment (Gupta *et al.*, 2004). Organic mulches of various plant/crop residues act as poor heat conductor consequently reducing soil temperature, conserving soil moisture and enhancing crop productivity (Amgain *et al.*, 2013).

In the post-green revolution era, resource-conservation issues have assumed greater importance in view of the widespread land and water degradation problems associated with mechanized intensive tillage system. Advancement of mechanization in modern conventional agriculture along with increasing demands of foods and other products, requires more fossil fuel energy, now has been realized as not very energy efficient and is detrimental to the air, water and soil environment. With aim of conserving resources, improving input-use efficiency and sustaining productivity, conservation agricultural system has emerged. Conservation agriculture with 3 principles of minimum soil disturbance (zero tillage), surface residue retention and effective crop rotations; have been found to conserve natural resources and enhance crop productivity through improved soil quality and water availability (Sharma *et al.*, 2012). Zero tillage technique is an ecological approach for soil surface management and seedbed preparation resulting less weed problem, better crop residue management and higher or equal yield (Mishra and Singh, 2012). Zero tillage and permanent bed planting along with crop-residue retention increased soil aggregation, total soil nitrogen and soil organic carbon in 0–30 cm soil profile (Bhattacharyya *et al.*, 2013; Das *et al.*, 2013). Permanent raised-bed and residue retention under zero tillage enhanced crop yield, profitability and water-use efficiency of maize–wheat (Ram *et al.*, 2012) and of cotton–wheat system (Das *et al.*, 2014). Fresh raised bed saved irrigation water and showed higher yield despite higher cost of cultivation, however, zero tillage with several benefits was not suitable and found uneconomical in heavier textured soil (Singh *et al.*, 2011). These reports indicate that the effects of tillage on crop yields were variable and location-specific, but it was possible to achieve the same crop yield at lower production cost with zero tillage along with mulching. Maize is grown during the rainy season (*khariif*) from June to October and wheat during winter season (*rabi*) from November to March/April. The land generally remains fallow between the harvest of wheat and sowing of maize. To satisfy the third pillar of conservation

agriculture, greengram was grown as a cover crop during summer under assured irrigation facility. Productivity and economics have hardly been studied in 3-crop cropping system under conservation agriculture. With this view, the present work was undertaken with an objective to study the effect of tillage, crop-establishment techniques and residue-management practices on the performance of irrigated maize (rainy)–wheat (winter)–greengram (summer) system.

MATERIALS AND METHODS

A field experiment was conducted on a fixed layout of split plot design during the monsoon, winter and summer seasons of 2011–12 and 2012–13 at the research farm of Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi. Four main plot treatments comprised tillage and crop-establishment techniques to maize–wheat sequence were: conventional tillage–flat bed (CTF), conventional tillage–raised bed (CTB), zero tillage–flat bed (ZTF) and zero tillage–raised bed (ZTB). Four subplot treatments comprised residue management practices were no residue control (CON), 2.5 tonnes wheat residue/ha (WR) in maize crop, 2.5 tonnes maize residue/ha (MR) in wheat crop and 2.5 tonnes wheat residue + 2.5 tonnes maize residue/ha (WMR) in both the crops. Crop residues were incorporated through tillage in conventional tillage, but retained on the soil surface in zero-tillage treatments. On this layout, previously cotton–wheat system was adopted for 3 years (2008–11) with the same treatment combinations, but with cotton residue in place of maize residue. The cropping system was changed to maize–wheat–greengram since June 2011 in order to attain higher crop and system productivity with better soil health by including a legume crop in rotation.

The soil was sandy loam (63.7% sand, 17.0% silt and 19.3% clay). The physico-chemical properties of the soil in various plots varied due to treatments applied in the previous cotton–wheat rotation. The average soil reaction was slightly alkali (pH 8.13 with soil and water ratio 1:2) and electrical conductivity 3.13 dS/m, low to medium in organic carbon (4.3–6.6 g/kg), low in available N (172–220 kg/ha), medium in available P (13.1–16.2 kg/ha) and medium to high available K (250–288 kg/ha). The variation in bulk density was 1.42 to 1.53 Mg/m³ and that of infiltration rate was 0.83 to 1.36 cm/h. New Delhi has a sub-tropical semi-arid climate with normal annual rainfall of 650 mm of which nearly 80% is received during monsoon period from July to September. The annual pan evaporation is about 850 mm. Higher and relatively well-distributed rainfall was received during 2012–13 (668 mm) as compared to 2011–12 (583 mm). The amount of rainfall received during rainy, winter and summer was

528, 34, and 21 mm during 2011–12 and 471, 176 and 21 mm during 2012–13. There were slight variations in mean air temperature, relative humidity and sunshine hours during both the years. However, the mean evaporation during rainy and summer was higher (5.4 and 9.2 mm/d) in the second year than the first year (4.0 and 8.8 mm/d).

In conventional tillage, ploughing was done with a tractor-drawn disc plough followed by harrowing and planking to have a uniform seed-bed of fine tilth. Tractor-drawn bed planter was used in addition to make fresh alternate raised beds (40 cm top width) and furrows (30 cm) in CTB. No ploughing was done in zero tillage, only reshaping of permanent raised beds in ZTB was done at sowing. Greengram was grown as a uniform crop during summer under zero-till condition; and its residues were retained in all subplots treatments except CON. Maize (cv. 'DHM 117' in 2011, 'HQPM 1' in 2012) was sown manually with minimum soil disturbance by narrow-opener hand plough at the seed rate of 20 kg/ha and row space of 70 cm uniformly in all the plots. Wheat (cv. 'HD 2894') was sown mechanically at seed rate of 100 kg/ha and row space of 20 cm by seed-cum-fertilizer drill in CTF and by zero-till seed-cum-ferti drill in ZTF. Same seed rate of wheat was applied by bed planter in CTB and ZTB to establish three crop rows per raised bed. Greengram (cv. 'SML 668') was sown mechanically under zero-till condition in all the plots at seed rate of 20 kg/ha and row space of 35 cm in flat planting and 2 rows per raised bed in bed planting.

A blanket spraying of herbicide, glyphosate 1.0 kg/ha was done before sowing of maize and wheat in zero-tilled plots. Herbicide, paraquat 1.0 kg/ha was applied before sowing of greengram to facilitate zero-till sowing in all the plots. All these crops were raised with standard package of practices with uniform doses of fertilizers and crop-protection chemicals. A common dose of 120 kg N + 60 kg P₂O₅ + 40 kg K₂O/ha was applied in both maize and wheat, and 100 kg DAP (18% N + 46% P₂O₅)/ha was applied in greengram. In maize and wheat crop, full doses of P and K and half the dose of N were applied basal at sowing. The remaining N in wheat was top-dressed in 2 equal splits after the first and second irrigation. In maize, the remaining N was top-dressed 35 days after sowing. In greengram, all the amount of fertilizer was applied at sowing. Depth of irrigation water varied with the crop-establishment method, it was 7 cm in flat planting and 5 cm in bed planting. In maize, pendimethalin 0.75 kg/ha along with atrazine 0.75 kg/ha was sprayed as pre-emergence tank-mix at 1 day after sowing (Das, 2008). However, 1 hand-weeding along with inter-culturing was done in conventional tillage at 30–40 days after sowing. To manage weeds in wheat, isoproturon 0.75 kg/ha along with 2, 4-D 0.25 kg/ha was applied as post-emergence 30 days after

sowing. No hand-weeding was required in wheat though interculturing was done at tillering stage in conventional tillage. Only pendimethalin 1.0 kg/ha was applied as pre-emergence in greengram. Chlorpyrifos (0.5%) and endosulfan (0.07%) were applied to control insect-pests when required. At maturity, number of cobs in net plot area of maize crop was counted and calculated for 1 m² for estimating yield attribute of maize, i.e. cobs/m². The total numbers of grains were counted from randomly selected 5 cobs of the net plot area, and grains/cob was estimated. Number of spike-bearing tillers of wheat crop were counted from 0.5 m² area randomly from 4 spots in the net plot area, averaged and estimated as number of spikes/m². Ten spikes from the sampled plants were randomly selected, threshed and numbers of grains/spikes were estimated. Number of pods/plant of greengram was taken at maturity from an area of 0.5 m². Grains were separated from 20 randomly selected pods and counted to estimate number of grains/pod. Samples of all the crops were harvested manually from the central net areas for yield assessment. Maize cobs were harvested by hand plucking and grains were separated by hand shelling. Rest wheat crop of the experimental field was harvested by a combine harvester. Threshing of wheat was done by using Pullman Thresher. Two pickings of pods of summer greengram were taken, and grains were separated by manual threshing. Grain yields of each crop were recorded from the net plot area. System productivity was calculated in terms of maize–grain-equivalent yield (MGEY) on the basis of prevailing minimum support price (MSP) of grains during 2011–12 and 2012–13. Economics of the system included the revenue from the residues of all the crops at local market price. Water productivity was calculated in terms of irrigation water-use efficiency, i.e. kilogram dry weight of grains produced/unit (m³) irrigation water applied. Similarly, energy productivity was estimated by dividing grain yield by total input energy consumed, expressed in kilogram/mega joule (kg/MJ). Energy productivity measures the utilization of energy required for a given agricultural product was recommended as an improved substitute of energy ratio. Energy coefficients were adopted from various available literatures (Chaudhary *et al.*, 2009; Devasenapathy *et al.*, 2009) to estimate input energy required in terms of MJ/ha.

The year-wise as well as 2-year data on crop productivity, system productivity, gross income, net income, benefit: cost, water productivity and energy productivity were subjected to the analysis of variance (ANOVA) in a split plot design using PROC GLM in the statistical software package SAS 9.3 version. Homogeneity of variances was tested by *F*-test for pool analysis of the 2 years data. The least square means (LSM) of respective treatments ob-

tained in pooled analysis were compared by least significant difference (LSD) at $p < 0.05$. The significant effect of treatment interaction on these parameters was compared in terms LSM in the graphics developed in the software package. The actual values are not given in the graphics and can be used only for comparing interactions of treatments in pooled analysis. Interactions of treatments in the graphics are shown by 2-digit numbers. Tillage and crop establishments in main plots (mp) are at 10 places of the 2-digit numbers and are given as 1 for CTF, 2 for CTB, 3 for ZTF, 4 for ZTB. Similarly, residue managements in subplots (sp) are at ones place of the 2-digit numbers and are given as 1 for CON, 2 for WR, 3 for MR, 4 for WMR (Fig. 1–6).

RESULTS AND DISCUSSION

Yield attributes of crops

The result showed remarkable variation in yield attributes of maize, wheat and greengram crops due to tillage and crop establishment and residue management practices (Table 1). Except grains/cob of maize, higher value of cobs/m² was observed on raised beds in 2011, while it was almost same on flat and raised beds in 2012. Generally higher or comparable values of cob/m² and grains/cob in zero tillage and on raised beds were observed during both the years. Application of crop residues also resulted higher values of these yield attributes during both the years. This might be due to early and better establishment

of maize on zero tillage and raised beds with residue retention, as these might helped to maintain favourable soil moisture, moderate soil temperature and improve nutrient condition (Ram *et al.*, 2010; Amgain *et al.*, 2013).

Among yield attributes of wheat, spikes/m² were improved, but grains/spike remained unaffected due to tillage and crop establishment in both 2011–12 and 2012–13. The value of spike/m² was significantly higher with flat beds compared to raise beds both in zero and conventional tillage. This result indicates that wheat crop sown on flat beds at uniform 20-cm-row spacing led to increase only number of spike/m² than on raised beds, accommodating 3 rows per raised bed of 40 cm top width followed by furrow of 30 cm width. Similar to the yield attributes of maize, yield attributes of wheat also improved owing to residue application with maximum in WMR. Ram *et al.* (2010) reported comparable or higher number of effective tillers and grains/spike in zero and conventional tillage. Sharma *et al.* (2002) reported water deficit-reduced tillering on raised beds compared to flat beds in sandy loam soil.

The yield attributes of zero-tilled greengram (pods/plant and grains/pod) was not affected due to tillage and crop-establishment practices, but tended to remain higher in the raised beds during both 2012 and 2013. These attributes were significantly higher with WMR, except grains/pod in 2012. This might be owing to better nodulation on raise beds (Dhindwal *et al.*, 2006) and higher ni-

Table 1. Yield attributes of maize, wheat and greengram influenced by tillage, crop-establishment and residue-management practices

Treatment	Maize				Wheat				Greengram*			
	2011		2012		2011–12		2012–13		2012		2013	
	Cobs/m ²	Grains/cob	Cobs/m ²	Grains/cob	Spikes/m ²	Grains/spike	Spikes/m ²	Grains/spike	Pods/plant	Grains/pod	Pods/plant	Grains/pod
<i>Tillage and crop-establishment</i>												
CTF	5.6	339	5.5	378	314	48.8	318	47.2	15.0	9.4	13.1	9.3
CTB	6.1	365	5.7	365	278	51.7	254	49.3	15.7	9.7	14.0	9.7
ZTF	5.9	362	6.3	376	324	48.9	315	47.4	15.0	9.4	13.0	9.4
ZTB	6.1	366	6.2	352	285	50.6	263	49.7	15.2	9.6	14.1	9.7
SEm±	0.08	8.7	0.09	8.9	2.7	1.5	5.2	1.2	0.27	0.21	0.44	0.23
CD (P=0.05)	0.3	NS	0.3	NS	9.0	NS	18.0	NS	NS	NS	NS	NS
<i>Residue-management</i>												
CON	5.6	342	5.8	343	276	48.7	272	46.4	14.4	9.3	12.3	9.2
WR	5.9	364	5.9	378	284	49.9	284	48.5	15.5	9.5	13.8	9.5
MR	5.9	359	5.9	362	299	50.5	292	48.8	15.1	9.4	13.3	9.4
WMR	6.2	367	6.0	388	342	50.9	304	50.0	15.9	9.9	14.8	10.0
SEm±	0.05	5.7	0.09	7.8	2.8	1.0	2.4	0.7	0.35	0.17	0.32	0.15
CD (P=0.05)	0.2	17.0	NS	23.0	8.0	NS	7.0	2.1	1.0	NS	0.9	0.4

CTF, Conservation tillage with flat bed planting; CTB, conservation tillage with raised bed planting; ZTF, zero tillage with flat bed planting; ZTB, zero tillage with raised bed planting; CON, no residue control; WR, Wheat residue in maize crop; MR, maize residue in wheat crop; WMR, wheat+maize residue in maize and wheat crop. *Greengram in the cropping system was grown under zero-tilled condition throughout the tillage treatments

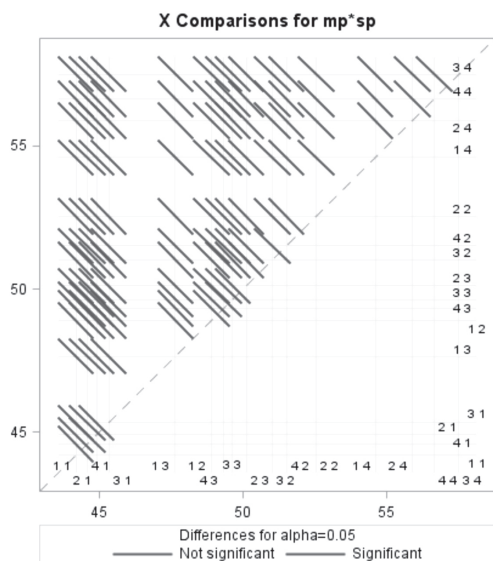


Fig. 1. Comparison of interaction ($mp \times sp$) for pooled system productivity (LSM)

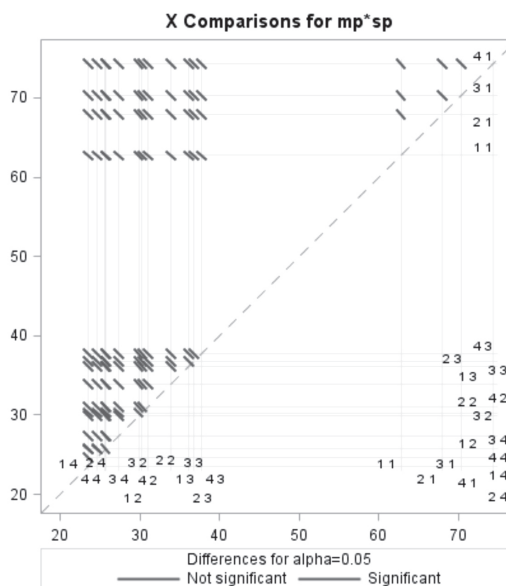


Fig. 3. Comparison of interaction ($mp \times sp$) for system energy productivity (LSM)

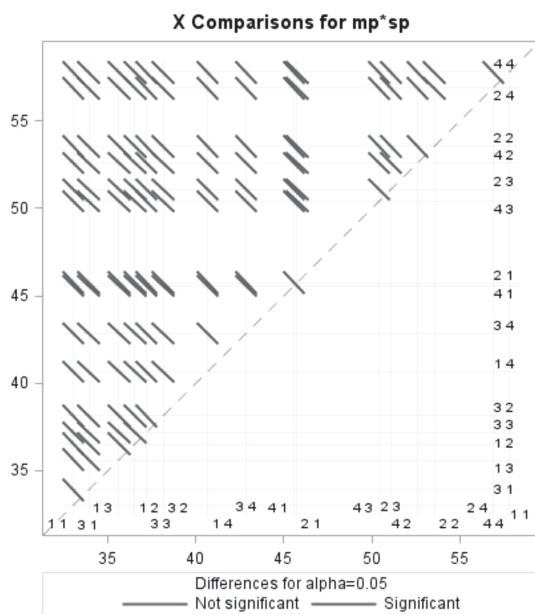


Fig 2. Comparison among interaction ($mp \times sp$) for pooled system IWUE (LSM)

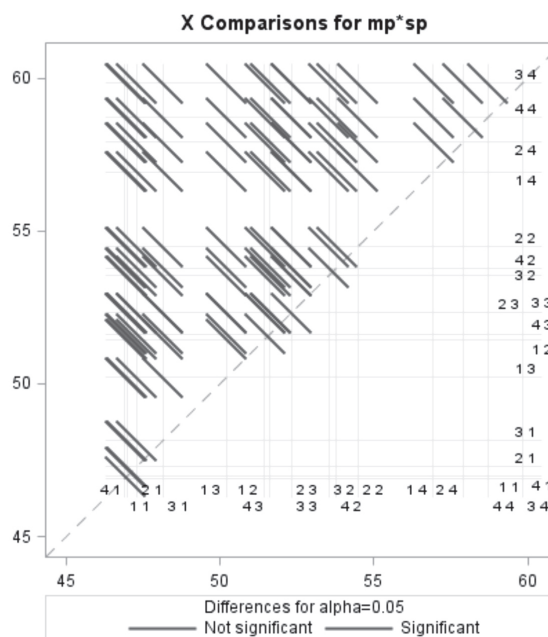


Fig. 4. Comparison of interaction ($mp \times sp$) for pooled system gross income (LSM)

trogen fixation due to residue mulching.

Crops and system productivity

The yield of maize (Table 2) was higher in zero-tillage (ZTB and ZTF), and was not influenced by crop-establishment technique under zero-till condition. Maize grain yield on zero-till soil was 8.5% higher than on conventionally-till soil. Among residue-management treatments, the highest maize grain yield was recorded in WMR, and it was significantly in the order of $WMR > WR > MR > CON$. In contrast to maize, wheat yield was not influenced by

tillage but differed significantly due to crop-establishment technique. The highest grain yield of wheat was recorded in CTF and ZTF. As compared to raised-bed, the yield of wheat was about 6.0% higher on flat-bed. The narrow raised-bed (40 cm top width and 30 cm furrow width) accommodating 3 rows/raised-bed might have not produced enough productive tillers to compensate the number of plant rows (20 cm apart) on the same land area of flat-bed. Closer spacing of wheat crop on these raised-beds prob-

ably increased the competition for resources among plants, subsequently produced lower yields. Ram *et al.* (2012) reported higher wheat yield on narrow raised-bed accommodating 2 rows/raised-bed, possibly owing to better canopy photosynthesis in wider spacing, producing longer spikes which compensated lower tiller and spike density compared to flat-bed. The grain yield in zero tillage was similar to the conventional tillage in the present study. Consistent with this findings, Sharma *et al.* (2012) recorded similar grain yield of wheat under conventional and zero tillage. As with maize, the grain yield of wheat was significantly higher in the WMR treatment, however with different order of WMR>MR>WR>CON. The zero-tilled greengram tended to remain higher on the raised-bed of CTB and ZTB; however, it was significantly higher in the CTB. Inclusion of greengram in the double cereal-based crop rotation following conservation agricultural practices was also suggested as future drivers of agricultural change in the north-western IGP (Gathala *et al.*, 2013).

System crop productivity in terms of maize grain-equivalent yield (MGEY) in ZTF, CTB and ZTB were almost equal (13.0–13.2 t MGE/ha), and were significantly higher (~5%) than the yield of CTF (Table 2). Such result on system productivity was outcome of effects of different tillage and crop-establishment treatments on yield of maize, wheat and greengram in sequence. Application of wheat and maize residue (WMR) in the crop cycle resulted significantly highest MGEY. The interaction effect was also significant on system productivity and showed that higher MGEY was observed in ZTF × WMR and ZTB × WMR followed by CTB × WMR (Fig. 1). Residue retention in zero tillage increased crop yields more than their soil incorporation in conventional tillage. Zero tillage and residue retention improve soil organic C, microbial biomass C, dehydrogenase activity, earthworm population and water availability, consequently results in good crop growth and productivity (Ghosh *et al.*, 2010; Das *et al.*, 2013).

Resource-use efficiency

Water productivity and energy productivity responded differently to different tillage and crop establishment and residue-management practices (Table 2). The pooled water productivity was significantly higher with ZTB in maize, with ZTB and CTB in wheat, and with CTB in zero-tilled greengram. However, the water productivity of the

Table 2. Crop, water and energy productivity of maize, wheat, greengram and system in terms of least square mean (LSM) influenced by tillage, crop-establishment and residue-management practices (pooled data of 2 years*)

Treatment	Crop productivity (t/ha)			Water productivity (kg/m ³)			Energy productivity (kg/MJ)		
	Maize	Wheat	System [§]	Maize	Wheat	System [§]	Maize	Wheat	System [§]
Tillage and crop-establishment									
CTF	22.7(4.52)	45.7(4.47)	17.9(0.82)	48.8(12.6)	17.3(2.21)	37.6(1.24)	15.6(0.29)	36.4(1.43)	43.6(0.159)
CTB	24.4(4.81)	43.2(4.19)	20.7(0.95)	50.9(13.1)	26.1(3.40)	47.3(1.53)	25.4(0.47)	51.8(2.03)	43.9(0.159)
ZTF	25.7(5.12)	45.3(4.43)	17.8(0.81)	50.9(13.2)	19.6(2.48)	37.3(1.23)	15.7(0.29)	38.0(1.49)	46.5(0.170)
ZTB	25.4(5.02)	43.2(4.20)	19.3(0.88)	50.5(13.0)	27.2(3.51)	47.2(1.54)	23.7(0.44)	51.6(2.02)	47.7(0.173)
SEM±	0.22	0.23	0.23	0.22	0.22	0.23	0.25	0.22	0.21
CD (P=0.05)	0.61	0.64	0.65	0.63	0.61	0.64	0.71	0.63	0.60
Residue-management									
CON	22.2(4.39)	41.7(4.06)	15.3(0.69)	44.8(11.6)	20.3(2.62)	39.8(1.30)	16.2(0.30)	39.6(1.55)	64.1(0.233)
WR	25.2(5.00)	43.3(4.22)	19.9(0.91)	51.0(13.2)	23.2(2.98)	41.4(1.35)	21.2(0.39)	45.2(1.77)	66.7(0.243)
MR	23.8(4.72)	45.3(4.40)	17.8(0.81)	49.2(12.7)	21.8(2.79)	43.2(1.41)	18.9(0.35)	43.6(1.70)	24.9(0.090)
WMR	27.1(5.36)	47.2(4.62)	22.8(1.04)	56.2(14.5)	24.9(3.22)	45.0(1.48)	24.1(0.45)	49.6(1.94)	26.0(0.095)
SEM±	0.22	0.23	0.23	0.22	0.22	0.23	0.25	0.22	0.21
CD (P=0.05)	0.61	0.64	0.65	0.63	0.61	0.64	0.71	0.63	0.60

CTF, Conservation tillage with flat bed planting; CTB, conservation tillage with raised bed planting; ZTF, zero tillage with flat bed planting; ZTB, zero tillage with raised bed planting; CON, no residue control; WR, Wheat residue in maize crop; MR, maize residue in wheat crop; WMR, wheat+maize residue in maize and wheat crop

*Figures within parentheses indicate 2 years mean data of actual values of yield (t/ha), water productivity (kg/m³) and energy productivity (kg/MJ); treatments are compared based on LSM obtained under pooled analysis using statistical software package SAS 9.3

§Calculated in terms of maize–grain-equivalent yield (MGEY) based on MSP of all the crops during 2011–12 and 2012–13

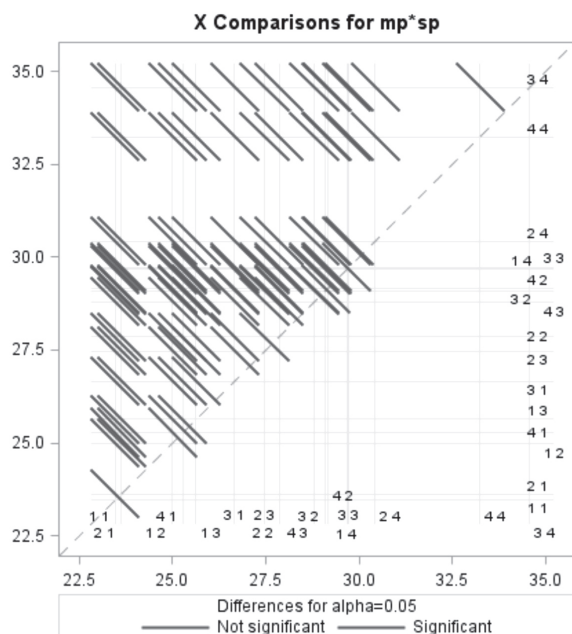


Fig. 5. Comparison of interaction ($mp \times sp$) for pooled system net returns (LSM)

cropping system in ZTB was comparable to CTB, both were significantly superior to ZTF and CTF. Application of wheat and maize crop residues (WMR) recorded the highest water productivity in all the crops in the system. The interaction effect in the system was significantly higher with ZTB \times WMR closely followed by CTB \times WMR (Fig. 2). This result might be owing to primarily saving of irrigation water in raised beds (Karunakaran and Behera, 2013).

The energy productivity was significantly higher with ZTB. Among the tillage and crop-establishment practices, the lowest energy was consumed with ZTB, saving energy by about 8.0% compared to CTF (not shown in the Table) in the system. Conventional tillage is regarded to be energy intensive and poor in resource utilization. Zero tillage reduced the energy requirement due to saving of energy in land preparation and weeding operation. Further, raised bed planting saved energy through irrigation as less water was applied compared to flat bed planting. Energy productivity was significantly higher with ZTB \times CON followed by ZTF \times CON (Fig. 3). Residue application lowered the energy productivity as huge energy was consumed through residues. Crop residues improved mainly soil quality when returned to soil. Besides quantity, the methods of residue application as surface retention in zero tillage had mulch effect, resulting better soil condition and crop productivity.

Economics

The total cost of cultivation of each crop varied due to

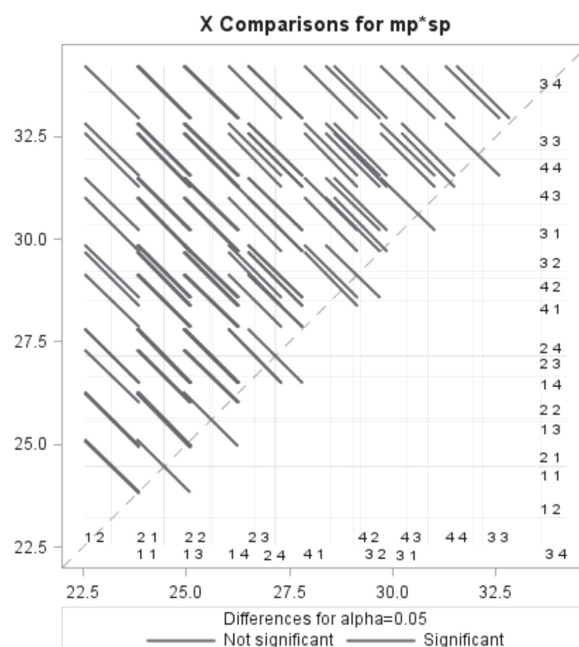


Fig. 6. Comparison of interaction ($mp \times sp$) for pooled system benefit: cost (LSM)

tillage, crop establishment and residue management practices (Table 3). This was mainly due to differences in land preparation, planting method and weed control/herbicide application across the treatments of tillage, crop establishment and residue application followed in each crop. In maize and wheat, the cost in the conventional tillage (CTF and CTB) were around 11–12% higher than the zero tillage (ZTF and ZTB) treatments. The cost was higher in raised-bed of maize (2.4%), whereas it was similar in raised-bed and flat-bed of wheat. The cost variation in maize was due to bed planter, used to make fresh-CTB or reshaping of permanent-ZTB before sowing of maize. Sowing was done manually on both the flat and raised-beds. In case of wheat, sowing was done by seed drill on the flat-beds and by bed planter on the raised-beds. Greengram was sown under zero till condition by seed-drill throughout the tillage treatment, therefore no difference of total cost was observed due to tillage treatment. The variation of cost in greengram was only due to residue application. The gross income, net returns and benefit: cost of maize and wheat were significantly higher in ZTF and WMR. In zero-till greengram, these were significantly higher in the CTB and WMR. The highest total cost in the cropping system was observed in the CTB (₹80.3 thousand/ha), while it was least in the ZTF (₹73.4 thousand/ha) with a difference of 9.4% (Table 3). The total system cost in WMR was 16.5% higher than the CON. The gross income, net returns and benefit: cost (B:C) of all crops in the cropping system differed significantly, depending on

Table 3. Economics of maize, wheat, greengram and system in terms of least square mean (LSM) influenced by tillage, crop-establishment and residue- management practices (pooled data of 2 years[§])

Treatment	Maize			Wheat			Greengram			System						
	Total cost	Gross income	Net returns	Total cost	Gross income	Net returns	Total cost	Gross income	Net returns	Total cost	Gross income	Net returns				
<i>Tillage and crop-establishment</i>																
CTF	29.0	25.4 (56.3)	12.3 (27.3)	11.8 (0.94)	30.6	53.0 (69.0)	29.3 (38.4)	27.8 (1.25)	20.0	18.8 (35.3)	8.1 (15.3)	8.1 (0.76)	79.6	51.4 (160.5)	25.9 (80.9)	24.9 (1.01)
CTB	29.7	27.3 (59.8)	13.9 (30.1)	12.9 (1.02)	30.6	49.8 (64.1)	26.1 (33.5)	24.7 (1.10)	20.0	21.6 (40.6)	10.9 (20.6)	11.1 (1.04)	80.3	52.8 (164.5)	27.3 (84.2)	26.1 (1.05)
ZTF	25.9	28.6 (63.6)	16.9 (37.7)	18.0 (1.45)	27.6	52.8 (68.6)	31.4 (41.0)	32.9 (1.49)	20.0	18.7 (35.2)	8.1 (15.3)	8.1 (0.76)	73.4	53.5 (167.5)	30.0 (94.1)	31.3 (1.28)
ZTB	26.5	28.5 (62.5)	16.5 (36.0)	17.1 (1.36)	27.6	49.7 (64.1)	28.3 (36.5)	29.7 (1.33)	20.0	20.3 (38.2)	9.6 (18.2)	9.7 (0.90)	74.1	53.0 (164.9)	29.1 (90.8)	30.1 (1.22)
SEm±	-	0.21	0.21	0.22	-	0.23	0.23	0.23	-	0.23	0.23	0.23	-	0.23	0.23	0.23
CD (P=0.05)	-	0.61	0.61	0.61	-	0.65	0.65	0.65	-	0.64	0.64	0.64	-	0.65	0.65	0.66
<i>Residue-management</i>																
CON	25.4	24.9 (54.8)	13.4 (29.4)	14.8 (1.17)	27.8	48.6 (62.8)	27.0 (35.0)	28.3 (1.26)	17.5	16.1 (30.4)	6.8 (13.0)	7.8 (0.73)	70.7	47.3 (148.1)	24.8 (77.4)	26.9 (1.10)
WR	29.4	28.1 (62.0)	14.7 (32.6)	13.8 (1.11)	27.8	50.2 (65.1)	28.7 (37.3)	29.9 (1.34)	22.5	20.8 (39.2)	8.9 (16.7)	7.9 (0.74)	79.7	53.3 (166.3)	27.8 (86.6)	26.8 (1.09)
MR	26.7	26.6 (58.9)	14.7 (32.2)	15.5 (1.23)	30.3	52.2 (67.4)	28.7 (37.1)	27.5 (1.23)	17.5	18.6 (35.1)	9.3 (17.6)	10.7 (1.00)	74.5	51.6 (161.4)	27.9 (86.9)	28.9 (1.17)
WMR	29.6	30.2 (66.4)	16.7 (36.8)	15.7 (1.26)	30.3	54.2 (70.6)	30.7 (40.3)	29.4 (1.33)	22.5	23.7 (44.6)	11.8 (22.1)	10.6 (0.98)	82.4	58.3 (181.6)	32.0 (99.2)	29.8 (1.21)
SEm±	-	0.21	0.21	0.22	-	0.23	0.23	0.23	-	0.23	0.23	0.23	-	0.23	0.23	0.23
CD (P=0.05)	-	0.61	0.61	0.61	-	0.65	0.65	0.65	-	0.64	0.64	0.64	-	0.65	0.65	0.66

CTF, Conservation tillage with flat bed planting; CTB, conservation tillage with raised bed planting; ZTF, zero tillage with raised bed planting; ZTB, zero tillage with flat bed planting; CON, no residue control; WR, Wheat residue in maize crop; MR, maize residue in wheat crop; WMR, wheat+maize residue in maize and wheat crop

[§]Figures within parentheses indicate 2 years actual mean data (thousand ₹/ha) and treatments are compared based on LSM obtained under pooled analysis using SAS 9.3; mean data of total cost under each treatments are expressed in thousand ₹/ha

the production level and cost incurred under each treatment. The gross income, net returns and benefit: cost of the system were significantly higher in ZTF. Overall ZTF fetched the highest net returns ₹ 94.1 thousand/ha and benefit: cost 1.28, became most remunerative tillage practice in the cropping system. The WMR registered significantly higher gross income, net returns and benefit: cost in the system. The interaction effect was also significant and showed significantly maximum gross income, net returns and B:C in ZTF supplemented with WMR (Figs. 4, 5 and 6).

Undoubtedly, zero tillage (ZTF and ZTB) and residue retention have potential to improve the crop productivity, profitability, efficiency of water-use. However, such study should be continued on a long-term basis with expectation of further improvement in overall performance to eventually make best recommendation for wider adoption.

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