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Review/Overview

Effect of resource-conserving and planting techniques on productivity of maize (*Zea mays*)–wheat (*Triticum aestivum*) cropping system

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ABSTRACT

A field experiment was conducted on a silty clay loam soil of Palampur during 2009–2011, to study effect of tillage and planting-management techniques in maize (*Zea mays* L.)–wheat {*Triticum aestivum* (L.) emend. Fiori & Paol.) cropping system. Zero tillage in rainy (*kharif*) and winter (*rabi*) seasons resulted comparable yield as with multi-crop planter, manual seed drill and conventional tillage methods. However, multi-crop planter and manual seed drill in the rainy season produced significantly higher effective plants/m^2 of maize (8.0 and 7.8, respectively). In case of wheat, conventional tillage in the rainy season produced significantly the highest effective spikes/m^2 (322.6) over the other treatments. However, multi-crop planter in the winter season produced significantly the highest effective spikes/m^2 (337.6). Water productivity in the rainy season was minimum under zero tillage (41.3 kg maize grain equivalent yield (mey)/ha-mm) and maximum under manual seed drill (48.5 kg mey/ha-mm), while water use was the lowest under manual seed drill and the maximum under zero tillage. System's total energy output was the highest with conventional tillage in the rainy season and multi-crop planter in the winter season. In maize crop, manual seed drill and multi-crop planter in the rainy season produced significantly lower total weed count at 60 days after sowing (DAS). Similarly, the total weed dry weight 90 days after sowing (DAS) was lowest under manual seed drill. In wheat crop, multi-crop planter, manual seed drill and conventional tillage in the winter season produced significantly lower weed count (at 30 and 60 DAS respectively) compared to zero tillage. Seeding with zero tillage, multi-crop planter and manual seed drill in the rainy season and the winter season could save 9, 11.5 and 6 man-days and 22, 16 and 9 man-days, respectively, over the conventional tillage.

Key words **:** Crop production, Conventional tillage, Maize–wheat cropping system, Water productivity, Zero tillage

Wheat and maize, respectively are the world's second and third most important cereal crops after rice. Besides providing nutrients for human/animals, maize serves as a basic raw material for the production of starch, oil, protein, alcoholic beverages and food sweeteners. Maize–wheat is the dominant cropping system in the sub-mountainous western Himalayan region of India. The contribution of this cropping system to total foodgrain production of the country is considerably large, being 36.49% of wheat (93.90 million t) and 8.38% of maize (21.57 million t) (GoI, 2012). In spite of the significant achievement made in research and development, productivity of maize–wheat system is very low. In Himachal Pradesh, the system is taken on 70% of net sown areas, mostly under rainfed conditions as 80% of cultivated area lacks irrigation facilities (Saroch *et al.,* 2012). The expansion of irrigation facilities for covering large area is not possible due to scattered small land holdings on undulating topography of the region. Further, nutrient deficiency, particularly of N and unchecked weed growth inflict considerable reduction in grain yield. Erosion due to runoff on sloping lands causes loss of soil, water and nutrients, leading to low productivity (Bhardwaj and Sindwal, 1998). In hilly areas, zero or minimum tillage technology is not much popular due to the small and scattered sloppy lands. Cultivating crops after ploughing with bullock-drawn implements is still a common feature in small land holdings. Small and scattered holdings, poor socio-economic conditions, little mechanization, together with the soil and climatic constraints prevent hill farmers to adopt modern technology as practiced by their counterparts in the adjoining plains.

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Modern agro-techniques (which involves intensive tillage) in agro-ecosystem has threatened the environment safety and natural resource base, especially the land and water. Further, intensive ploughing due to elaborate tillage opereations exposes the soil to increased erosion losses (Dogra *et al.,* 2002) thus may not be suited to hilly areas already prone to excessive soil-erosion hazards. Further, various studies have shown that in many cases tillage operations as intensive as practiced are not actually required. Intensive tillage also increases the cost of cultivation and consumes large amount of energy. Thus, it becomes imperative to sustain the productivity of agricultural systems concomitant with friendly environment and efficient utilization of production resources. Therefore, an experiment was conducted to study the effect of tillage and planting management techniques in maize–wheat cropping system**.**

MATERIALS AND METHODS

A field experiment was conducted from the rainy season (*kharif*) 2009 to winter season (*rabi*) 2010-11 at Palampur (32^{0}6' N, 76^{0}3' E and 1,290 m altitude) in the North-West Himalayas. The site falls in the Sub-Temperate Mid Hill Zone of Himachal Pradesh. The region is endowed with mild summers and cool winters. The soil was silty clay loam, moderately acidic in reaction (*p*H 5.06), high in organic carbon (1.1%) and phosphorus (25.8 kg/ha) and medium in available N (323.0 kg/ha) and K (276.4 kg/ha). The maize crop was raised exclusively under rainfed conditions. During the season (June to September, *kharif*), the crop experienced well distributed rainfall of 1,342.1 and 2,148.0 mm during 2009 and 2010 respectively. During the wheat-growing season (November to May, *rabi*), the crop received 361.9 and 557.2 mm rainfall during 2009–10 and 2010–11, respectively, besides the crop was irrigated 4 times (pre-sowing, at crown-root initiation, jointing and flowering) in 2009–10 and 5 times (pre-sowing, at crown-root initiation, tillering, jointing and flowering) during 2010–11. The irrigation was given 5 cm each time. Prior to the commencement of the present study, the field was under rice–wheat experimentation with similar set of treatments.

Maize–wheat system was raised in sequence with 16 treatment combinations in strip–plot design with 3 replications. Treatments in horizontal plots were (Maize, *kharif*): M_1, sowing by power tiller-operated zero till drill; M_2, sowing by power tiller-operated multi-crop planter; M_3, sowing by manually operated seed drill; M_4, sowing by conventional method (sowing behind the hand plough); and in vertical plots (wheat, *rabi*): W_1, sowing by power tiller-operated zero till drill; W_2, sowing by power tiller-operated multi-crop planter; W_3, sowing by manually operated seed drill; W_4, sowing by conventional method (sowing behind the hand plough). Maize 'Girija Composite' and wheat 'HPW 155' were sown during both the years under irrigated conditions. The recommended dose of N, P_2O_5 and K_2O for maize and wheat was 120:60:40 and 120:60:30 kg/ha respectively. Entire P and K were applied at sowing to both the crops. In maize, N was applied in 3 equal splits (at sowing, knee-high and tasseling stage) whereas in wheat, half N at the time of sowing and remaining N was applied in 2 splits at tillering and earing stage. To control the weeds Atrazine at 1.25 kg/ha followed by (fb) 2,4-D at 1.00 kg/ha in maize crop and Isoproturon at 1.20 kg/ha fb. 2,4-D at 1.00 kg/ha in wheat crop were applied during both years. However, at later growth period of crops, weeds were also removed manually. The weed count and weed dry weight data were analysed after subjecting the original data to square root transformation ($\sqrt{X+0.5}$) and the treatment effects were compared using transformed means. The energy output (MJ/ha) of each crop was worked out by multiplying the energy coefficients with grain and straw (Rana *et al*., 2011). Similarly, the energy input (MJ/ha) for individual crop was worked out by adding energy used in different inputs used and operations carried out. Energy output : input ratio was obtained by dividing energy output (MJ/ha) with energy input (MJ/ha). Water productivity (kg maize equivalent yield/ha-mm water) was worked as per Rana *et al.,* (2011). Complete record was maintained for the resources (time, energy and labour) saved. In order to work out the most profitable treatment, the economics of each treatment was worked out on the basis of prevalent market prices of the inputs and output. Since data obtained over the year done at same experimental site followed the homogeneity test, pooling was done over the seasons and mean data are given. The data obtained were statistically analyzed as per Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Tillage on maize

Among the yield-attributing characters, tillage methods during *kharif* significantly influenced the effective plant population of maize at harvest (Table 1). Multi-crop planter (M_2) being statistically at par with manual seed drill (M_3) and conventional tillage (M_4) resulted in significantly higher effective plant population/m^2 over zero tillage (M_1). This may be owing to higher growth and development of crop right from early stages and less crop–weed competition in these treatments. However, depressing effect of no tilling was not reflected in cobs/plant or weight of the cob. Green cob and stover yield were not significantly influenced by tillage methods in *kharif* and *rabi*. Ram *et al.* (2010) also reported comparable yield under different tillage treatments.

Table 1. Effect of planting techniques on yield attributes and yield of maize (pooled data of 2 years)

Treatment	Effective plants/m² at harvest	Cobs/plant	Weight/cob (kg)	Green cob yield (t/ha)	Stover yield (t/ha)
Kharif					
Zero tillage (M_1)	7.0	1.40	0.26	6.49	45.43
Multi-crop planter (M_2)	8.0	1.33	0.24	7.40	42.77
Manual seed drill (M_3)	7.8	1.39	0.26	8.06	44.01
Conventional tillage (M_4)	7.7	1.40	0.26	7.39	45.45
SEm±	0.12	0.03	0.01	0.47	1.38
CD (P=0.05)	0.4	NS	NS	NS	NS
Rabi					
Zero tillage (W_1)	7.6	1.37	0.25	7.20	43.98
Multi-crop planter (W_2)	7.7	1.41	0.25	7.41	45.27
Manual seed drill (W_3)	7.5	1.38	0.27	7.66	43.45
Conventional tillage (W_4)	7.8	1.36	0.25	7.07	44.96
SEm±	0.19	0.04	0.01	0.35	0.81
CD (P=0.05)	NS	NS	NS	NS	NS

Tillage on wheat

Tillage methods in *kharif* significantly influenced effective spikes/m² of wheat (Table 2). Conventional seeding (M_4) resulted in significantly highest effective spikes/m². In case of tillage methods in *rabi,* multi-crop planter (W_2) produced significantly highest effective spikes/m². These results may be ascribed to less crop–weed competition in the plots. Also, better soil conditions made easy availability of nutrients from deeper layers. The 1,000-grain weight and grain yield were not affected by tillage methods. These results are in line with those reported by Ram *et al.* (2010). Like maize cob yield, wheat grain yield was not significantly different either owing to tillage treatments in *kharif* or in *rabi*. This comparable effect of tillage and planting treatments indicated that one can follow any method of his choice at least for the initial years.

Water use and productivity

Irrigation water application was uniform in all the treatments. Thus variation in water productivity (kg maize equivalent yield/ha-mm water applied) was owing to variation in yield under different treatments. Water productivity under treatments in *kharif* varies from 41.3 to 48.5 kg mey/ha-mm with minimum under zero tillage and maximum under manual seed drill (Table 3). The increase in water productivity in manual seed drill was achieved owing to increase in total grain production per unit water used. Conversely, water use (litre/kg MEY) varied from 207 to 244, being lowest under manual seed drill and the highest under zero tillage. Water productivity under treatments in the winter season varied from 43.6 to 46.6 kg MEY/ha-mm with minimum under zero tillage and the maximum under multi-crop planter. Likewise in the rainy

Table 2. Effect of planting techniques on yield attributes, grain and straw yield of wheat (pooled data of 2 years)

Treatment	Effective spikes/m²	Grains/spikes	1,000-grains weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Kharif					
Zero tillage (M_1)	299.2	42.4	51.1	3.58	5.01
Multi-crop planter (M_2)	305.0	41.6	51.6	3.54	5.07
Manual seed drill (M_3)	283.5	43.4	50.1	3.58	5.28
Conventional tillage (M_4)	322.6	43.8	51.3	3.67	5.39
SEm±	2.08	0.97	1.04	0.14	0.14
CD (P=0.05)	7.2	NS	NS	NS	NS
Rabi					
Zero tillage (W_1)	286.3	43.0	51.5	3.30	4.89
Multi-crop planter (W_2)	337.6	41.8	50.1	3.88	5.38
Manual seed drill (W_3)	291.1	43.8	49.9	3.56	5.09
Conventional tillage (W_4)	295.3	42.6	52.7	3.63	5.38
SEm±	8.75	0.75	1.70	0.12	0.18
CD (P=0.05)	30.3	NS	NS	NS	NS

season, exactly opposite trend was observed for water use, being lowest in multi-crop planter and the highest in zero tillage. Water productivity and water use were determined based upon irrigation water only. The soil profile water and rain water was not taken in account.

Energetics

The results on input and output energy and energy output: input ratio are given in (Table 3). The data revealed that tillage and planting techniques in the rainy season resulted in higher input energy under multi-crop planter (M_2). However, conventional tillage (M_4) resulted in the highest output energy and output : input energy ratio. Data on tillage and planting techniques in *rabi* revealed that multi-crop planter (W_2) resulted in highest system's total energy output. However, the output : input ratio was highest under conventional tillage (W_4) and the lowest under zero tillage (W_1).

Weeds

Weed flora in maize crop was mainly composed of *Ageratum conyzoides* (L.) (57 and 70% respectively at 60 and 90 DAS), *Polygonum alatum* (L.) (19 and 10% respectively) and *Commelina benghalensis* (L.) (7 and 6% respectively). The other weeds (*Echinochloa colona* (L.) Link, *Panicum dichotomiflorum* (L.), *Eleusine indica* (L.), *Digitaria sanguinalis* (L.) and *Cyperus* spp.) as a whole constituted 17 and 14% respectively, at 60 and 90 DAS. Chopra and Angiras (2010) also reported association of these weeds with maize crop.

Tillage methods in the rainy season significantly influenced total weed count at 60 DAS and total weed dry weight at 90 DAS (Table 4). Total weed count was significantly highest in zero tillage (M_1), followed by conventional tillage (M_4). This may be due to large number of weed seeds present on the soil surface in zero-tilled plots. The result confirms the findings of Arif *et al.* (2007) and Cardina *et al.* (2002). Multi-crop planter (M_2) and manual seed drilling (M_3) seeding were statistically at par with each other for total weed count. Manual seed drilling (M_3) in the rainy season resulted in significantly lowest total weed dry weight than the other planting techniques at 90 DAS. Zero till drilling (M_1), multi-crop planter seeding (M_2) and conventional seeding (M_4) were statistically at par with each other in influencing the total weed dry weight. Low weed dry weight in manual seed drill (M_3) may be due to delay in emergence of weeds which may be due to the presence of less moisture content in the top layer. Tillage or planting techniques in the winter season neither affected total weed count nor the total weed dry weight at any observational stage in maize.

Weeds in wheat

In wheat, at maximum weed population stage (90 DAS), the weed flora was composed of *Vicia sativa* L. (38 and 39% during 2009–10 and 2010–11 respectively), *Lolium temulentum* (L.) (25 and 30%), *Avena ludoviciana* Durieu (25 and 15%), *Anagallis arvensis* (L.) (8 and 15%) and *Phalaris minor* Retz. (4 and 8%). In spite of some common weed-management strategies undertaken during the crop-growth period, tillage or planting techniques in the rainy season significantly influenced total weed population in wheat at 30 DAS. All the tillage-management techniques in the rainy season, *viz.* zero till seeding (M_1), multi-crop planter (M_2) and manual seed drill seeding (M_3), showed significantly lower total weed count than conventional seeding (M_4). Tillage methods in the winter season significantly influenced total weed count at 30 and 60 DAS. Generally, zero tillage (W_1) resulted in significantly more weeds than other tillage methods. This may be due to more weed seeds in the top layer of undisturbed soil in these plots. The total weed dry weight was not signifi-

Table 3. Effect of planting techniques on irrigation water productivity, water use, energy ($\times 10^3$ MJ/ha/annum) in maize–wheat cropping system (pooled data of 2 years)

Treatment	Water productivity (kg MEY/ha-mm)	Water use (l/kg MEY)	Input energy (MJ/ha)	Output energy (MJ/ha)	Output: input energy ratio
Kharif					
Zero tillage (M_1)	41.3	244	31.6	650.5	20.6
Multi-crop planter (M_2)	45.7	219	32.0	630.1	19.7
Manual seed drill (M_3)	48.5	207	31.8	652.1	20.6
Conventional tillage (M_4)	45.6	221	31.8	664.2	20.9
Rabi					
Zero tillage (W_1)	43.6	229	31.8	636.3	20.0
Multi-crop planter (W_2)	46.6	215	32.3	665.1	20.7
Manual seed drill (W_3)	46.4	217	31.5	640.1	20.4
Conventional tillage (W_4)	44.4	226	31.6	655.4	20.8

cant during both the years (Data not shown).

Soil health

Soil pH, organic carbon (OC) and bulk density after the harvesting maize and wheat during 2009–2011 are given in Table 5. Tillage or planting techniques in in the rainy season could significantly influence soil pH after the harvest of maize during 2010 and after harvest of wheat during 2010–11. Multi-crop planter (M_2) and zero till seeding (M_1) had higher pH over conventional tillage (M_4) and manual seed drill (M_3). This may be ascribed to increased levels of organic matter in no-tilled soil. These results are in accordance with Doran (1980). Tillage or planting technique in the rainy season significantly influenced the organic carbon (%) after harvest of wheat crop (2009–10). Zero tillage (M_1) being statistically at par with multi-crop planter (M_2) resulted in significantly higher organic carbon over conventional tillage (M_4) and manual seed drill (M_3) Doran (1980) also reported more organic carbon in zero tillage, which was due to more moisture, less oxidative plus cumulative effect of decomposed roots. These conditions might have tended to cause the organic matter content to increase. Tillage or planting techniques in the winter significantly influenced the bulk density after wheat

Table 4. Effect of planting techniques on total weed count (No./m^2) and dry weight (g/m^2) in maize and total weed count (No./m^2) in wheat (pooled data of 2 years)

Treatment	Maize				Wheat		
	Weed count		Weed dry weight		Weed count		
	60 DAS	90 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Kharif							
Zero tillage (M_1)	18.3 (336.8)	19.6 (385.5)	4.7 (22.1)	9.2 (85.2)	6.9 (50.2)	6.6 (45.8)	8.6 (75.0)
Multi-crop planter (M_2)	16.0 (255.2)	20.3 (411.5)	4.3 (18.6)	9.1 (82.6)	7.0 (51.2)	6.9 (50.5)	9.6 (93.3)
Manual seed drill (M_3)	15.9 (254.2)	19.4 (375.3)	4.4 (18.9)	8.5 (72.8)	7.0 (51.7)	6.8 (49.5)	9.5 (94.3)
Conventional tillage (M_4)	17.2 (295.0)	19.5 (382.0)	4.5 (20.0)	9.1 (82.3)	8.1 (68.3)	7.4 (56.3)	9.3 (92.7)
SEm±	0.25	0.28	0.13	0.12	0.24	0.16	0.30
CD (P=0.05)	0.9	NS	NS	0.4	0.8	NS	NS
Rabi							
Zero tillage (W_1)	17.3 (302.8)	19.7 (389.5)	4.4 (19.1)	8.8 (77.2)	9.7 (94.8)	9.2 (85.5)	11.6(137.8)
Multi-crop planter (W_2)	17.0 (291.0)	19.7 (389.5)	4.6 (20.7)	9.1 (83.5)	6.3 (40.8)	6.1 (37.7)	8.3 (69.8)
Manual seed drill (W_3)	16.4 (268.2)	19.6 (385.8)	4.5 (19.9)	8.9 (79.9)	6.7 (45.2)	6.2 (39.0)	8.9 (80.7)
Conventional tillage (W_4)	16.7 (279.2)	19.7 (389.5)	4.5 (19.9)	9.1 (82.2)	6.3 (40.5)	6.3 (40.0)	8.1 (67.0)
SEm±	0.28	0.38	0.08	0.29	0.63	0.56	0.92
CD (P=0.05)	NS	NS	NS	NS	2.2	2.0	NS

Values in parentheses are the averages of original values

Table 5. Effect of planting techniques on pH, OC (%) and BD (g/cm^3) of soil in maize-wheat cropping system

Treatment	2009(After maize)			2009–10(After wheat)			2010(After maize)			2010–11(After wheat)		
	pH	OC	BD	pH	OC	BD	pH	OC	BD	pH	OC	BD
Kharif												
Zero tillage (M_1)	5.06	1.11	1.17	5.04	1.12	1.16	5.22	1.11	1.30	5.24	1.12	1.31
Multi-crop planter (M_2)	5.13	1.10	1.20	5.05	1.10	1.17	5.28	1.14	1.34	5.25	1.13	1.30
Manual seed drill (M_3)	5.08	1.11	1.17	5.02	1.06	1.18	5.08	1.10	1.34	5.15	1.12	1.33
Conventional tillage (M_4)	5.04	1.11	1.20	5.04	1.07	1.18	5.18	1.11	1.31	5.19	1.10	1.30
SEm±	0.04	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.01	0.02	0.02	0.01
CD (P=0.05)	NS	NS	NS	NS	0.05	NS	0.06	NS	NS	0.05	NS	NS
Rabi												
Zero tillage (W_1)	5.07	1.13	1.19	5.05	1.09	1.23	5.21	1.08	1.35	5.19	1.13	1.37
Multi-crop planter (W_2)	5.07	1.12	1.19	5.01	1.11	1.16	5.21	1.10	1.31	5.23	1.12	1.28
Manual seed drill (W_3)	5.05	1.11	1.17	5.03	1.09	1.17	5.19	1.17	1.33	5.22	1.12	1.29
Conventional tillage (W_4)	5.12	1.07	1.17	5.05	1.06	1.13	5.17	1.10	1.32	5.18	1.10	1.29
SEm±	0.04	0.02	0.02	0.02	0.06	0.02	0.05	0.03	0.01	0.02	0.01	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	0.06	NS	NS	NS	NS	NS	0.05

OC, Organic carbon; BD, bulk density

Table 6. Economics of treatments in maize-wheat cropping system (pooled data of 2 years)

Treatment	Cost of cultivation ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Benefit: cost ratio
Kharif			
Zero tillage (M_1)	52.9	114.0	2.15
Multi-crop planter(M_2)	55.5	117.4	2.11
Manual seed drill (M_3)	54.0	127.9	2.37
Conventional tillage(M_4)	54.7	123.2	2.25
SEm±		6.02	0.11
CD (P=0.05)	-	NS	NS
Rabi			
Zero tillage (W_1)	53.4	116.1	2.17
Multi-crop planter (W_2)	55.8	124.3	2.23
Manual seed drill (W_3)	55.3	120.9	2.19
Conventional tillage(W_4)	52.7	121.2	2.30
SEm±		2.92	0.05
CD (P=0.05)	-	NS	NS

Cost of maize green cob and wheat grain each during both years ₹10,000/t; maize fodder ₹1,000/t during both years; wheat straw 3,000 and 4,000/t, during 2009–10 and 2010–11, respectively.

during 2009–10 and 2010–11. Zero tillage (W_1) resulted in significantly highest bulk density over other treatments during both seasons. The higher bulk density under zero tillage may be due to decrease in volume of the soil due to fewer disturbances. These results confirm the findings Ram *et al.* (2010).

Economics

Due to comparable yields, tillage or planting methods in the rainy season could not bring significant variation in net return and benefit: cost ratio in maize–wheat cropping system (Table 6). However, zero tillage (M_1) had the lowest cost of cultivation over other treatments due to less machinery used, as the primary tillage was completely skipped. Cost of inputs, viz. labourers, fertilizer, herbicide, field preparation and sowing (including seed) in maize crop under zero tillage was ₹6,270, 6,257, 1,000, 440, 2,745/ha respectively, under multi-crop planter ₹5,720, 6,257, 1,000, 3,220, 3,065/ha respectively; under manual seed drill ₹5,720, 6,257, 1,000, 3,220, 1,595/ha respectively; and under conventional tillage ₹6,270, 6,257, 1,000, 3,220, 1,925/ha respectively. In case of net return and benefit: cost ratio, manual seed drill (M_3) resulted in higher returns over other treatments. Tillage treatments in the winter were not significantly different in influencing net returns and benefit: cost ratio. However, conventional tillage (W_4) had lowest cost of cultivation. Zero tillage (W_1) had lower cost of cultivation than multi-crop planter (W_2) and manual seed drill (W_3). In wheat crop during 2009–10 and 2010–11, cost of labourer, fertilizer, herbicide, field preparation and sowing (including seed) under zero tillage was ₹10,213, 8,760, 871, 920, 7,520/ha, respectively; under multi-crop planter ₹10,213, 8,760, 871, 3,250, 7,520/ha respectively; under manual seed drill ₹9,638, 8,775, 871, 3,250, 4,010/ha, respectively and under conventional tillage ₹9,638, 8,760, 8,71, 3,250, 5,045/ha respectively. Multi-crop planter (W_2) and conventional tillage (W_4) resulted in higher net returns and benefit: cost ratio respectively. The relative economics of different tillage treatments further inferred that farmers may choose any of the new method of their choice, but the zero tillage has been potentially beneficial by virtue of having lower energy, labour and time demand besides having environmental benefits. Seeding with zero tillage, multi-crop planter and manual seed drill in the rainy and the winter seasons could save 9, 11.5 and 6 man days and 22, 16 and 9 man days respectively, over the conventional tillage.

It can be concluded from these studies that seeding with zero till drill, multi-crop planter and manual seed drill was comparable to conventional seeding in terms of productivity and profitability of maize–wheat cropping system. Hence farmers may go for any of the tillage or planting techniques depending on the availability of the resources with them at least for the initial 1 or 2 years. However, power tiller operated multi-crop planter may have an edge over others in the long run.

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