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Tillage, Crop Establishment, and Weed Management for Improving Productivity, Nutrient Uptake, and Soil Physico-chemical Properties in Soybean-wheat Cropping System

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ABSTRACT

The effect of tillage (conventional and zero tillage), crop establishment (raised-bed and flat-bed), and weed management practices (herbicide alone and integrated approach) was studied on productivity, profitability, nutrient uptake and physico-chemical properties of soil in soybean–wheat cropping system, at New Delhi during 2010–2012. Sixteen treatment combinations consisting of four tillage and crop establishment practices, *viz*. Conventional Tillage–raised-bed (CT–bed), CT–flat-bed, Zero Tillage–raised-bed (ZT–bed) and ZT–flat-bed; and four weed management practices, *viz*. unweeded control, herbicide+Hand Weeding (HW), herbicide combination, and crop residue + herbicide were laid out in a split-plot design. Soybean produced higher seed yield (+7.6%) under raised-bed and wheat under flat-bed (+6.2%), but the system productivity was highest under CT–flat-bed. Pre-emergence application of pendimethalin followed by HW gave higher yield of soybean, while all weed control treatments were found equally good for wheat. Conventional tillage resulted in higher uptake by soybean of N (+5.0%), P (+4.4%) and K (+3.1%) than ZT, particularly under raised-bed conditions. In wheat, CT and ZT resulted in almost similar nutrient uptake under flat-bed. Total nutrient uptake of the system was similar for N and P under all tillage and crop establishment practices, while herbicide+HW gave 4.9–7.2% higher uptake than herbicide combination or crop residue+herbicide. Net benefit: cost ratio of the system was the highest (> 2.0) under ZT–flat-bed and herbicide combination. There was beneficial effect on physico-chemical properties of soil under ZT and residue application, but it is necessary to run the experiment in long-term to see the cumulative effect over time.

Keywords: Benefit, Cost ratio, Profitability, Raised-bed, Zero tillage.

INTRODUCTION

Soybean (*Glycine max* L. Merr.) is cultivated as rainy season crop in India on 8.88 M ha, producing 9.99 M t with average productivity of 1.12 t ha^{-1}. Wheat (*Triticum aestivum* L. emend. Fiori and Paol.) is the second most important cereal crop after rice, grown on 26 M ha and meets the nutritional requirement of the majority of the people (FAO, 2010). Both these crops contribute significantly towards the livelihood of large number of people engaged in their cultivation, trade, and processing. Soybean–wheat cropping system is commonly practiced in the semi-arid to sub-humid tropical Malwa and Vindhyan plateau regions of Madhya Pradesh on about 2.3 M ha. This belt contributes nearly 80% of the total soybean produced in the country. The average productivity of soybean (0.9 t ha^{-1}) and wheat (1.3 t ha^{-1}) in this cropping system is very low, owing to low soil

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fertility and other production constraints (Behera *et al.,* 2007). Major research and development efforts in the green-revolution era focused on enhancing productivity of a selected food grain crops. In the post-green revolution era, the issues of conservation have assumed greater importance in view of the widespread resource degradation problems and the need to reduce production costs, increase profitability, and make agriculture more competitive. Resource degradation problems are manifesting in several ways. Declining water tables in many agriculturally-important regions imply increasing pumping costs, replacement of shallow gravity tube wells with submersible pumps at huge cost, adverse effects on water quality and overall ecology of the region. Declining soil carbon and fertility are reflecting in loss of soil biodiversity, multiple nutrient deficiencies, increasing input use to maintain yields, and implications for quality of produce and environment.

Tillage is the basic and most important requirement of crop production. The efficiency of input use, viz. water, fertilizers, herbicides and others depends on tillage and crop establishment practices. Studies on no-tillage and bed planting technologies have largely been conducted in wheat in rice–wheat cropping system in the north-western plain zone (Behera *et al.,* 2007). There is already a greater emphasis on crop diversification due to growing concerns about the unsustainability of rice–wheat system in this region. In this context, a crop like soybean has emerged as the promising alternative for rice in rainy season in the northern India. However, weeds often pose serious constraints in realizing maximum yield of soybean and wheat, if not controlled at critical period of the first 30 days after sowing (Yaduraju and Mishra, 2002). These reduce the yield of soybean by 58─85%, depending on the weed species and the degree of infestation (Monsefi *et al.,* 2013). Several methods to control weeds, *viz.* cultural, mechanical, and chemical, have their own merits and demerits. Summer tillage is an age-old practice to control weeds (Kumar and Das, 2008). However, the periodicity of weed germination often limits its usefulness during rainy as well as in winter seasons. The crops that quickly form a shade canopy and are allelopathic in nature have an adverse impact on weeds sensitive to shade and can be adopted as a weed-control measure. Non-selective herbicides like paraquat and glyphosate control a broad-spectrum of weeds when applied as pre-sowing treatment under zero-tillage conditions. All these methods have been evaluated independently and also for a single crop or crop season. Literature indicates that no single method is effective and economical for a crop or cropping system. In view of the above considerations, adoption of modified tillage and crop establishment practices along with weed control and residue management is the need of hour as a method of 'low-input agriculture' to achieve sustainability in soybean−wheat cropping system. Accordingly, this study was planned to study the effect of different tillage practices, method of crop establishment, and weed management on productivity and profitability of soybean–wheat grown in sequence.

MATERIALS AND METHODS

A field experiment was conducted at the Indian Agricultural Research Institute, New Delhi (28^{o} 40' N, 77^{0} 12' E and altitude of 228 m above mean sea level) during rainy season of 2010-2011 and 2011-2012. The soil of the experimental field was sandy loam in texture with neutral pH (7.5), low in organic C (0.42%), $KMnO_4$–oxidizable N (174.4 kg ha^{-1}), and $NaHCO_3$–extractable P (17.2 kg ha^{-1}), and medium in NH_4OAc–exchangeable K (279.0 kg ha^{-1}). The soil moisture content at 1/3 and 15 atmospheric tensions was 19.8 and 7.8% mass basis, respectively, with bulk density of 1.54 Mg m^{-3} of surface layer (0–15 cm). There was high rainfall in 2010 (954 mm), while it

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was much less (-30.6%) in 2011. There was excess rainfall during July–August 2010, due to which, the growth of soybean was adversely affected. On the other hand, the rainfall was almost negligible in July 2011, which led to vigorous growth of soybean plants.

Both crops of soybean and wheat were raised in sequence in a fixed layout over the two cropping cycles. Previously, the field was under cotton–wheat cropping system for two cropping cycles (2008–09 and 2009–10) with four main plot treatments of Conventional Tillage (CT)–raised-bed, CT–flat-bed, Zero Tillage (ZT)–raised-bed and ZT–flat-bed. The present experiment was conducted in these plots in a split-plot design with three replications. Four tillage and crop establishment techniques, *viz*. CT–raised-bed, CT–flat-bed, ZT–raised-bed and ZT–flat-bed were allotted to the main plot; while four weed management treatments, *viz.* unweeded control, herbicide + hand weeding, herbicide combination, and crop residue+herbicide were allotted to sub-plots. In case of soybean, the four weed management treatments were: unweeded control, pendimethalin+hand weeding, pendimethalin+imazethapyr and wheat straw mulch+imazethapyr. In case of wheat, the following treatments were applied in the respective plots: unweeded control, isoproturon+hand weeding, mesosulfuron+iodosulfuron, soybean stover mulch+isoproturon. Plowing was done with a disc-harrow followed by cultivator and rotavator in CT plots, while no soil disturbance was done in ZT plots.

Soybean *cv*. 'DS 9814' was sown using seed-cum-fertilizer drill under CT and ZT flat-bed conditions at 35 cm row spacing. In case of raised-bed, sowing was done with the bed-planter (70 cm each bed) with two rows of soybean on the bed at 26 cm row spacing, on 10 July 2010, and 1 July 2011. A plant spacing of 5-7 cm was maintained after thinning at 20 DAS. A seed rate of 80 kg ha^{-1} along with recommended fertilizer dose of 20-26-33 kg N-P-K ha^{-1} was followed uniformly. Soybean matured in the first week of October. Wheat cv. 'HD 2894' was sown using seed-cum-fertilizer drill under CT and ZT flat-bed conditions at 20 cm row spacing. In case of raised-bed, sowing was done with the bed-planter (70 cm) with three rows of wheat on the bed at 13 cm row spacing, on 22 November 2010, and 11 November 2011. A seed rate of 100 kg ha^{-1} along with recommended fertilizer dose of 120-26-33 kg N-P-K ha^{-1} was followed uniformly. Wheat matured in the third week of April.

Paraquat at the rate of 0.5 kg ha^{-1} was sprayed in ZT plots one week before sowing. In case of soybean, pre-emergence application of 0.75 kg ha^{-1} pendimethalin was made within two days of sowing in the respective plots. Imazethapyr at the rate of 75 g ha^{-1} was applied at 15 DAS. Hand-weeding was done at 30 DAS with the help of hand-hoe. Five t ha^{-1} wheat straw mulch was applied after sowing. The crop was raised under irrigated conditions with one and three irrigations applied during 2010 and 2011, respectively. For wheat, 1.0 kg ha^{-1} isoproturon was applied at 30 DAS. Hand-weeding was done at 50 days of growth with the help of hand-hoe. Herbicide mixture, mesosulfuron (12 g)+iodosulfuron (2.4 g ha^{-1}) was applied at 30 DAS. Soybean stover mulch was applied at the rate of 3 t ha^{-1} after sowing. The crop was raised under irrigated conditions with three and four irrigations applied during 2010–2011 and 2011–2012, respectively.

Observations were recorded on yield performance, nutrient uptake, and soil physico-chemical properties. The seed and stover yields of soybean as well as grain and straw yield of wheat were recorded from the net plot area of 8.4 m^2. The seed yield of soybean and grain yield of wheat were adjusted at 14% moisture. The nutrient concentrations in seed/grain and stover/straw of crops were determined as per the standard methods, and the uptake values were calculated. The economic analysis in terms of gross and net returns, and benefit: cost ratio (net returns per rupee invested) was done on the basis of prevailing rate of inputs and output. Total variable cost included the cost of inputs, such as seeds, fertilizers, irrigation and various cultural operations, such as plowing, sowing, weeding, harvesting, threshing etc. At the end of two cropping cycles, bulk density of surface (0–5 cm) and sub-surface (5–15 cm) soil, hydraulic conductivity and infiltration rate were measured. Soil samples were analyzed for organic C, available N by alkaline $KMnO_4$ method, available P by 0.5M $NaHCO_3$ extraction, and available K by IN NH_4OAc extraction. The data recorded for different parameters were analyzed as per analysis of variance technique for a split-plot design using MSTAT-C software.

RESULTS AND DISCUSSION

System Productivity

System productivity in terms of soybean-equivalent yield was not influenced significantly due to tillage and crop establishment practices (Table 1). Although the seed yield of soybean was comparatively more under raised-bed than flat-bed, a reverse trend was noticed in wheat yield, i.e. the grain yield of wheat was lower under raised-bed than flat-bed. These opposite trends in the yield performance of the two crops resulted in non-significant differences in the overall system productivity among the tillage and crop establishment practices. On the other hand, the weed management treatments showed significant variation in the system productivity. The productivity improved with adoption of weed control through different methods, and the highest yield was obtained under W_2 (herbicide+hand weeding). The productivity under this treatment (W_2) was on par with crop residue+herbicide (W_4) but significantly more than the herbicide combination in 2010-2011. In 2011-2012, the highest productivity under herbicide+hand weeding was on par with herbicide combination, but significantly more than crop residue+herbicide. Nonetheless, all the treatments resulted in 28.7–31.5% increase in the overall system productivity compared with unweeded control. Interaction between tillage and crop establishment, and weed management practices were non-significant in both years. The similar results were reported by Sayre *et al*. (2005) and Sheibani and Ghadiri (2012).

Nutrient Uptake

Total N uptake of soybean–wheat cropping system was significantly influenced by tillage and crop establishment in 2010–2011, but not in 2011–2012 (Table 2). In 2010–2011, the highest N uptake was recorded under CT–raised-bed, which was on par with CT–flat-bed and ZT–raised-bed, but significantly more than ZT–flat-bed. In 2011–2012, the total N uptake was considerably more than 2010–2011, but the differences among different treatments were not significant. Weed management resulted in significant increase in N uptake in both years, the highest increase being under herbicide + hand weeding, followed by crop residue+herbicide and herbicide combination. Interaction effect was significant, suggesting variable increase in N uptake with weed management under different tillage and crop establishment practices. The effect of straw mulch was less pronounced under CT–flat-bed than under ZT–flat-bed.

Total uptake of P was more in 2011–2012 than 2010–2011 but it was not significantly influenced by tillage and crop establishment practices (Table 3). All treatments resulted in similar P uptake as the differences were small. This was despite the fact that P uptake of soybean in both years, and wheat P uptake in 2011–2012, was significantly influenced by tillage and crop establishment practices. The opposite trends of variation in the two crops led to non-significant differences in total P uptake of the system. On the other hand, weed management caused large increase in total uptake of P in both years. The highest total P uptake was obtained under herbicide+hand weeding, followed by crop residue+herbicide and herbicide combination. Interaction effect

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Table 1. Effect of tillage and crop establishment, and weed management practices on productivity of soybean–wheat cropping system (t ha^{-1}).

Treatment	Seed yield of soybean		Grain yield of wheat		System productivity (Soybean equivalent)	
	2010	2011	2010–2011	2011–2012	2010–11	2011-2012
Tillage and crop establishment (A)						
T_1 (CT– raised-bed)	1.59	1.89	4.29	4.39	4.16	4.52
T_2 (CT–flat-bed)	1.52	1.79	4.44	4.79	4.18	4.66
T_3 (ZT–raised-bed)	1.55	1.78	4.27	4.39	4.11	4.42
T_4 (ZT–flat-bed)	1.39	1.63	4.46	4.73	4.06	4.46
SEm$\pm$	0.04	0.05	0.09	0.10	0.06	0.07
CD (P= 0.05)	0.12	0.17	NS	0.34	NS	NS
Weed management (B)[a]						
W_1 (Unweeded control)	1.03	1.18	3.56	3.62	3.17	3.36
W_2 (Pendimethalin+HW)	1.71	2.06	4.67	4.96	4.52	5.03
W_3 (Pendimethalin+Imazethapyr)	1.62	1.95	4.52	4.92	4.33	4.90
W_4 (Crop residue+Imazethapyr)	1.68	1.89	4.69	4.81	4.49	4.77
SEm$\pm$	0.02	0.04	0.07	0.07	0.05	0.06
CD (P= 0.05)	0.07	0.12	0.20	0.20	0.14	0.19
Interaction (A×B)						
SEm$\pm$	0.05	0.08	0.14	0.14	0.09	0.13
CD (P= 0.05)	NS	NS	NS	NS	NS	NS

[a] In wheat, the weed management treatments were: W_1 (Unweeded control); W_2 (Isoproturon+HW); W_3 (Mesosulfuron+ Iodosulfuron), and W_4 (Crop residue+Isoproturon).

Table 2. Effect of tillage and crop establishment, and weed management practices on N uptake of soybean–wheat cropping system (kg ha^{-1}).

Treatment	2010–2011			2011–2012		
	Soybean	Wheat	Total	Soybean	Wheat	Total
Tillage and crop establishment (A)						
T_1 (CT– raised-bed)	135.2	88.5	223.7	156.3	95.6	251.8
T_2 (CT–flat-bed)	124.2	94.3	218.5	138.5	105.3	243.7
T_3 (ZT–raised-bed)	132.2	90.5	222.6	143.7	98.8	242.5
T_4 (ZT–flat-bed)	118.1	93.3	211.4	133.9	108.2	242.0
SEm$\pm$	2.53	1.01	2.53	3.04	1.51	3.27
CD (P= 0.05)	8.77	3.50	8.74	10.51	5.24	NS
Weed management (B)[a]						
W_1 (Unweeded control)	88.4	76.4	164.8	99.3	83.3	182.6
W_2 (Pendimethalin+HW)	149.4	98.3	247.7	167.5	110.8	278.3
W_3 (Pendimethalin+Imazethapyr)	134.8	95.0	229.8	151.8	106.6	258.4
W_4 (Crop residue+Imazethapyr)	137.0	96.9	233.9	153.8	107.1	260.8
SEm$\pm$	1.75	0.95	1.67	2.24	1.03	2.44
CD (P= 0.05)	5.11	2.78	4.89	6.54	3.01	7.11
Interaction (A×B)						
SEm$\pm$	3.50	1.90	3.35	4.48	2.06	4.88
CD (P= 0.05)	10.21	5.55	9.78	13.09	6.01	14.23

[a] In wheat, the weed management treatments were: W_1 (Unweeded control); W_2 (Isoproturon+HW); W_3 (Mesosulfuron+ Iodosulfuron), and W_4 (Crop residue+Isoproturon).

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Table 3. Effect of tillage and crop establishment, and weed management practices on P uptake of soybean–wheat cropping system (kg ha^{-1}).

Treatment	2010–2011			2011–2012		
	Soybean	Wheat	Total	Soybean	Wheat	Total
Tillage and crop establishment (A)						
T_1 (CT– raised-bed)	15.5	16.7	32.1	22.2	17.7	39.9
T_2 (CT–flat-bed)	14.9	17.6	32.6	20.8	19.6	40.4
T_3 (ZT–raised-bed)	15.5	16.8	32.3	21.1	18.3	39.3
T_4 (ZT–flat-bed)	14.0	17.6	31.6	19.7	19.9	39.6
SEm±	0.27	0.44	0.46	0.37	0.30	0.59
CD (P= 0.05)	0.94	NS	NS	1.28	1.03	NS
Weed management (B)[a]						
W_1 (Unweeded control)	10.9	14.6	25.5	15.2	15.6	30.8
W_2 (Pendimethalin+HW)	16.9	18.3	35.2	24.1	20.4	44.5
W_3 (Pendimethalin+Imazethapyr)	16.1	17.6	33.8	22.2	19.7	41.9
W_4 (Crop residue+Imazethapyr)	15.9	18.2	34.1	22.4	19.8	42.1
SEm±	0.21	0.33	0.35	0.29	0.24	0.40
CD (P= 0.05)	0.60	0.98	1.04	0.86	0.69	1.16
Interaction (A×B)						
SEm±	0.41	0.67	0.71	0.59	0.47	0.80
CD (P= 0.05)	NS	NS	NS	1.71	NS	2.33

[a] In wheat, the weed management treatments were: W_1 (Unweeded control); W_2 (Isoproturon+HW); W_3 (Mesosulfuron+ Iodosulfuron), and W_4 (Crop residue+Isoproturon).

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between tillage and crop establishment, and weed management on total P uptake was significant in 2011–2012. CT-flat-bed resulted in much higher P uptake, particularly under unweeded control than other tillage and establishment treatments. Further, the differences among different treatments of weed control were non-significant under ZT–flat-bed; but, under CT–flat-bed, herbicide+HW were significantly superior to herbicide combination and crop residue+herbicide.

Tillage and crop establishment practices resulted in significant influence on total K uptake of the system (Table 4). In 2010–2011, total K uptake was the highest under CT–flat-bed, followed by ZT–raised-bed, both of which, were significantly superior to other treatments. In 2011–2012, the highest total K uptake under ZT–flat-bed was significantly more than other tillage and crop establishment practices. These variable trends in the two years were due to the differences in yield (Table 1). Evidently, the weed management treatments resulted in large increase in total K uptake, the best treatment being herbicide+HW, followed by herbicide combination in 2010–2011, and crop residue+herbicide in 2011–2012. The effect of herbicide combination and crop residue + herbicide was on par in both years. Interaction between tillage and crop establishment and weed management practices was significant on total K uptake in both years. These results suggested that different treatments of weed management showed variable response under different tillage and crop establishment practices.

Economics

Total cost of cultivation as well as net returns were much higher for wheat than for soybean, and accordingly, the net B:C ratio was also more for wheat (Table 5). Soybean gave higher net returns under raised-bed, while wheat was more profitable under flat-bed, irrespective of tillage and crop establishment. Further, the system net

Table 4. Effect of tillage and crop establishment, and weed management practices on K uptake of soybean–wheat cropping system (kg ha^{-1}).

Treatment	2010–2011			2011–2012		
	Soybean	Wheat	Total	Soybean	Wheat	Total
Tillage and crop establishment (A)						
T_1 (CT– raised-bed)	88.6	96.4	185.0	99.7	114.2	213.9
T_2 (CT–flat-bed)	83.9	108.5	192.4	93.5	125.8	219.2
T_3 (ZT–raised-bed)	88.9	102.3	191.2	94.5	123.8	218.2
T_4 (ZT–flat-bed)	81.3	100.8	182.1	90.0	137.7	227.6
SEm$\pm$	1.57	1.04	1.41	1.70	1.91	1.72
CD (P= 0.05)	5.44	3.61	4.87	5.89	6.60	5.94
Weed management (B)[a]						
W_1 (Unweeded control)	65.3	89.8	155.1	70.8	110.4	181.2
W_2 (Pendimethalin+HW)	95.3	106.3	201.6	106.7	133.3	240.1
W_3 (Pendimethalin+Imazethapyr)	91.2	107.4	198.6	99.5	124.9	224.4
W_4 (Crop residue+Imazethapyr)	90.9	104.4	195.3	100.6	132.8	233.4
SEm$\pm$	1.47	1.62	2.39	1.28	2.47	3.18
CD (P= 0.05)	4.29	4.73	6.98	3.74	7.20	9.29
Interaction (A×B)						
SEm$\pm$	2.94	3.24	4.78	2.56	4.93	6.36
CD (P= 0.05)	NS	9.47	13.96	7.48	14.40	18.58

[a] In wheat, the weed management treatments were: W_1 (Unweeded control); W_2 (Isoproturon+HW); W_3 (Mesosulfuron+ Iodosulfuron), and W_4 (Crop residue+Isoproturon).

Table 5. Effect of tillage and crop establishment, and weed management practices on economics (×10^3 Rs[b] ha^{-1}) of soybean–wheat cropping system (mean data of 2 years).

Treatment	Soybean			Wheat			Soybean+Wheat		
	TCCc[b]	NR[d]	Net B : C ratio	TCC	NR	Net B : C ratio	TCC	NR	Net B : C ratio
Tillage and crop establishment									
T_1 (CT– raised-bed)	15.24	21.29	1.40	18.42	38.96	2.12	33.66	60.25	1.79
T_2 (CT–flat-bed)	14.94	19.75	1.32	18.12	43.13	2.38	33.06	62.88	1.90
T_3 (ZT–raised-bed)	14.11	20.93	1.48	17.31	40.36	2.33	31.42	61.29	1.95
T_4 (ZT–flat-bed)	13.81	17.97	1.30	17.01	44.01	2.59	30.82	61.97	2.01
Weed management (B)[a]									
W_1 (Unweeded control)	11.61	11.92	1.03	16.52	31.72	1.92	28.13	43.64	1.55
W_2 (Pendimethalin+HW)	15.79	23.78	1.51	18.97	44.77	2.36	34.76	68.55	1.97
W_3 (Pendimethalin+Imazethapyr)	14.69	22.79	1.55	17.44	45.01	2.58	32.13	67.79	2.11
W_4 (Crop residue+Imazethapyr)	16.01	21.45	1.34	17.92	44.97	2.51	33.93	66.42	1.96

[a] In wheat, the weed management treatments were: W_1 (Unweeded control); W_2 (Isoproturon+HW); W_3 (Mesosulfuron+ Iodosulfuron), and W_4 (Crop residue+Isoproturon).

[b] Rs. 60= 1 US $; [c] Total Cost of Cultivation, [d] Net Returns.

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returns were comparatively higher in 2011–2012 than in 2010–2011 due to higher productivity. The highest net returns of the soybean-wheat system were obtained under CT–flat-bed with herbicide+HW in accordance with the findings of Jat *et al.* (2005). This was closely followed by ZT–flat-bed with herbicide combination as well as crop residue+herbicide. ZT–raised-bed with herbicide combination, and ZT–flat-bed with herbicide+hand weeding and crop residue+herbicide also resulted in almost similar net returns. In terms of net B:C ratio, the best treatment was ZT–flat-bed with herbicide combination, which resulted in net B:C ratio of > 2.0. Weed management through herbicide+HW in soybean and herbicide combination in wheat proved superior to other treatments. These results suggested that zero tillage either with raised-bed or flat-bed could be equally good as conventional tillage for improving profitability of soybean-wheat cropping system.

Soil Physico-chemical Properties

Soil bulk density under ZT–flat-bed plots was relatively higher than the rest of the treatments (Table 6). This might be due to non-disturbance of the soil, which resulted in less total porosity compared to tilled plots. Down the profile (sub-surface), there was increasing trend in soil bulk density. Similar results were also reported by Obalum and Obi (2010) and Ram *et al.* (2010). Comparatively higher hydraulic conductivity was recorded under CT, while ZT gave the lowest value under both methods of crop establishment. Buschiazzo *et al*. (1998) observed that a period of 3-4 years was not enough for tillage to affect most properties of sandy loam and other soils in Argentinean Pampas. The increase of K_{sat} by tillage in the surface soil layer was probably due to continuous channels formed by decaying roots, which served as routes linking the soil surface to deeper layers. In ZT plots, the pore continuity was probably maintained due to better aggregate stability and pore geometry (Bhattacharyya *et al*., 2006). ZT-raised-bed resulted in highest infiltration rate (1.24 cm hr^{-1}), while the lowest value was under ZT-flat-bed (1.19 cm hr^{-1}). The infiltration rate was relatively higher under crop residue+herbicide than other weed control treatments. Water transmission through the soil profile depends on the antecedent water content, aggregation and the presence of macro-pore channels (Shaver *et al*., 2002 and Vaezi and Bahrami,

Table 6. Effect of tillage and crop establishment, and weed management practices on physical properties of soil in soybean-wheat cropping system (at the end of 2 cropping cycles).

Treatment	Bulk density (g cm^{-3})		Hydraulic conductivity (cm hr^{-1})		Infiltration rate (mm hr^{-1})
	0–15 cm	0–15 cm	0–15 cm	15–30 cm	
Tillage and crop establishment					
T_1 (CT– raised-bed)	1.54	1.77	1.35	1.12	1.22
T_2 (CT–flat-bed)	1.60	1.79	1.30	0.93	1.17
T_3 (ZT–raised-bed)	1.61	1.80	1.22	1.02	1.24
T_4 (ZT–flat-bed)	1.67	1.84	1.19	0.97	1.188
Weed management (B)[a]					
W_1 (Unweeded control)	1.64	1.79	1.29	1.03	1.17
W_2 (Pendimethalin+HW)	1.58	1.81	1.27	0.99	1.20
W_3 (Pendimethalin+Imazethapyr)	1.61	1.80	1.24	1.00	1.19
W_4 (Crop residue+Imazethapyr)	1.58	1.80	1.26	1.02	1.25

[a] In wheat, the weed management treatments were: W_1 (Unweeded control); W_2 (Isoproturon+HW); W_3 (Mesosulfuron+ Iodosulfuron), and W_4 (Crop residue+Isoproturon).

Table 7. Effect of tillage and crop establishment, and weed management practices on chemical properties of soil in soybean-wheat cropping system (at the end of 2 cropping cycles).

Treatment	Organic C (%)		Available nutrients (kg ha^{-1})			pH
	0-15 cm	15-30 cm	N	P	K	
Tillage and crop establishment						
T_1 (CT– raised-bed)	0.61	0.47	195.8	19.2	304.0	7.43
T_2 (CT–flat-bed)	0.60	0.47	196.3	18.7	302.0	7.39
T_3 (ZT–raised-bed)	0.61	0.46	200.4	19.3	308.8	7.36
T_4 (ZT–flat-bed)	0.60	0.47	202.5	19.0	312.0	7.44
SEm±	0.006	0.006	3.28	0.41	4.06	0.08
CD (P= 0.05)	NS	NS	NS	NS	NS	NS
Weed management (B)[a]						
W_1 (Unweeded control)	0.60	0.46	194.1	18.4	305.7	7.44
W_2 (Pendimethalin+HW)	0.60	0.46	198.5	19.3	304.2	7.38
W_3 (Pendimethalin+Imazethapyr)	0.60	0.46	199.9	18.9	307.5	7.47
W_4 (Crop residue+Imazethapyr)	0.62	0.49	202.5	19.6	309.4	7.33
SEm±	0.005	0.007	3.40	0.34	4.56	0.10
CD (P= 0.05)	NS	NS	NS	NS	NS	NS

[a] In wheat, the weed management treatments were: W_1 (Unweeded control); W_2 (Isoproturon+HW); W_3 (Mesosulfuron+ Iodosulfuron), and W_4 (Crop residue+Isoproturon).

2014). The higher infiltration in the plots under ZT was due to minimum disturbance that maintained the continuity of water conducting pores (Acharya and Sood, 1992) and bio-channels (Azooz *et al*., 1996).

There was no change in organic C of the soil due to tillage and crop establishment as well as weed control practices (Table 7). Similarly, the available nutrient and pH also did not vary with any of the treatments. The beneficial effect of crop residue application was also not evident on organic C and available nutrients despite addition of 16 t ha^{-1} of residues of soybean and wheat over a period of two cropping cycles. Such results are expected in soils of low organic matter status in sub-tropical regions and the build-up of soil fertility may take several years of continuous residue addition.

CONCLUSIONS

It was concluded that better performance of soybean in raised-bed and wheat in flat-bed resulted in higher system productivity and profitability under CT–flat-bed. Integrated weed management and crop residue + herbicide application was beneficial for sustainability of soybean-wheat cropping system on sandy-loam soils of a sub-tropical region.

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چکیده

در این تحقیق اثر شیوه شخم (سنتی (شخم) و حفاظتی (بدون شخم))، نحوه کاشت و استقرار گیاه (جوی پشته و مسطح) و نحوه مدیریت علف های هرز (کاربرد علف کش و روش تلفیقی) در میزان عملکرد، سازگاری، میزان عناصر غذایی و خصوصیات فیزیکی و شیمیایی خاک تحت کشت سیستم سویا–گندم در طی سال های ۲۰۱۰–۲۰۱۲ در دهلی مورد بررسی قرار گرفت. تیمارها به صورت ۱۶ تیمار ترکیبی شامل ۴ تیمار مربوط به شخم و نحوه استقرار گیاه (شخم–جوی پشته، شخم–مسطح، بدون شخم–جوی پشته و بدون شخم–مسطح) و ۴ تیمار دیگر مربوط به نحوه مدیریت علف های هرز (بدون حذف علف های هرز، علف کش+حذف دستی، کاربرد ترکیبی علف کش و بقایا+علف کش) در نظر گرفته شد و تحت طرح آماری کرت های خرد شده کاملا تصادفی در۳ تکرار اجرا گردید. از لحاظ میزان تولید بذر عملکرد گیاه سویا در تیمار جوی پشته (۷/۶+ درصد) و گیاه گندم در کشت مسطح (۶/۲+ درصد) افزایش معنی داری را نشان داد ولی به طور کلی بیشترین عملکرد سیستم در حالت شخم و کشت مسطح مشاهده گردید. استفاده از علف کش پندیمیتالین قبل از مرحله جوانه زنی و به دنبال آن وجین دستی علف های هرز باعث حداکثر افزایش میزان عملکرد سویا گردید در حالیکه در مورد گندم تیمار های کنترل علف هرز به صورت موثر و برابر میزان عملکرد را افزایش داد. در مورد سویا سیستم شخم سنتی نسبت به سیستم بدون شخم باعث افزایش جذب عناصر نیتروژن (۵/۰+ درصد)، فسفر (۴/۴+ درصد) و پتاسیم (۳/۱+ درصد) بویژه در شرایط کشت جوی پشته گردید. در مورد گندم شخم سنتی و بدون شخم نتایج کاملاً مشابهی را از لحاظ میزان عناصر جذب شده در شرایط کشت مسطح نشان داد. میزان کل جذب عناصر غذایی نیتروژن و فسفر در زمینه تیمار شخم و نحوه کاشت مشابه بود در حالیکه در مورد تیمار علف کش+وجین دستی ۴/۹ تا ۷/۲ درصد مقادیر بیشتری نسبت به استفاده از ترکیب علف کش ها و یا استفاده از بقایا+علف کش مشاهده گردید. سود خالص سیستم در شرایط بدون شخم، کشت مسطح و استفاده ترکیبی علف کش ها بیشترین مقدار (بیشتر از ۲) گزارش شد. به طور کلی شرایط بدون شخم و استفاده از بقایا آثار سودمندی را بر شرایط فیزیکی و شیمیایی خاک نشان داد اما آنچه مهم به نظر می رسد ادامه این تحقیق در طی زمان بیشتر و مشاهده اثرات تجمعی این فاکتورها بر بهبود وضعیت خاک است.