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Research Paper

Conservation tillage and weed management for improving productivity, nutrient uptake and profitability of soybean (*Glycine max*) grown after wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was conducted during 2010 and 2011 at New Delhi to study the performance of soybean [*Glycine max* (L.) Merrill] grown after wheat [*Triticum aestivum* (L.) emend Fiori & Paol] under four tillage and crop establishment practices, *viz.* conventional tillage (CT)–flat-bed, CT–raised-bed, zero tillage (ZT)–flat-bed and ZT–raised-bed along with four weed management options, *viz.* unweeded control, pendimethalin @ 0.75 kg/ha as pre-emergence (PE) + hand weeding (HW), pendimethalin @ 0.75 kg/ha as PE + imazethapyr @ 75 g/ha as post-emergence (POE), and wheat straw mulch @ 5 t/ha + imazethapyr @ 75 g/ha as POE. Total weed density and dry matter was comparatively higher under ZT than CT, but adoption of chemical + cultural weed control methods led to 79.5-82.5% weed control efficiency. Seed yield of soybean was equal under CT–raised-bed, CT–flat-bed and ZT–raised-bed, which was 11.7% more than ZT flat-bed. Similarly, pendimethalin + HW, pendimethalin + imazethapyr, and wheat straw mulch + imazethapyr resulted in almost similar weed control, and thus gave comparable seed yield, which was 39.1–42.7% higher than unweeded control. Weed and crop biomass followed opposite trends, and the seed yield decreased by 0.2 t/ha for an increase of 100 g/m^2 in weed dry weight. Concentration of N, P and K in seed and stover of soybean was not influenced but the uptake was highest under CT–raised-bed, which was on par with ZT–raised-bed. Nutrient uptake was highest under pendimethalin + HW, which was significantly higher than under pendimethalin + imazethapyr, and wheat straw mulch + imazethapyr. The highest net benefit:cost was under ZT–raised-bed and pendimethalin + imazethapyr or pendimethalin + HW, followed by CT–raised-bed under the same weed control treatments. It was concluded that soybean can be grown under permanent raised-bed with pre- and post-emergence herbicides for realizing higher productivity and profitability.

Key words : Conservation tillage, Nutrient uptake, Raised-bed, Soybean, Weed, Wheat residue, Zero tillage

Soybean–wheat cropping system is commonly practised in the semi-arid to sub-humid tropical Malwa and Vindhyan Plateau regions of Madhya Pradesh on about 4.5 Mha (Behera *et al*., 2007). This belt contributes nearly 80% of the total soybean produced in the country. The average productivity of soybean (0.9 t/ha) and wheat (2.8 t/ha) in this cropping system is low, owing to poor soil fertility and other production constraints. Of late, the production costs in agriculture have increased tremendously but the returns have declined due to indiscriminate use of various resources. Studies on zero-tillage and bed planting technologies have largely been conducted in wheat in rice–wheat cropping system in the north-western plain zone. There is already a greater emphasis on crop diversification due to growing concerns about the unsustainability of this system in the 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 a serious constraint in realizing potential yield of soybean (Kumar *et al*., 2012; Younesabadi *et al*., 2013a, 2013b) if not controlled at critical period of first 30 days after sowing. These reduce the yield by 58–85%, depending on the weed species and the degree of infestation (Balyan *et al*., 1999). Several methods to control weeds, *viz.* cultural, mechanical and chemical have their own merits and demerits. Some herbicides like pendimethalin and imazethapyr are effective (Jadhav and Gadade, 2012; Upadhyay *et al*., 2012; Younesabadi *et*

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al., 2013a, 2013b), but these need to be integrated with other methods for season-long weed control. Non-selective herbicides like glyphosate and paraquat also need to be used as pre-sowing treatment under zero-tillage conditions. An integrated approach involving appropriate method of tillage, crop establishment and weed control may help in optimizing productivity of soybean. Accordingly, a study was undertaken to evaluate the effect of tillage, crop establishment and weed control on productivity, profitability and nutrient uptake of soybean grown after wheat.

MATERIALS AND METHODS

A field experiment was conducted at the Indian Agricultural Research Institute, New Delhi (28° 40′N, 77°12′E and altitude of 228 m above mean sea level) during rainy season of 2010 and 2011 on a soil sandy-loam in texture with neutral pH (7.5), low in organic C, $KMnO_4$-oxidizable N and $NaHCO_3$-extractable P, and medium in NH_4OAc-exchangeable K. The soil moisture content at 1/3 and 15 atmospheric tensions was 19.8 and 7.8%, 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 was much less (–30.6%) in 2011. The excess rainfall during July–August 2010 hampered seedling growth but there was vigorous growth of plants in 2011 due to optimum rainfall.

The field was under cotton–wheat cropping system during the previous two years, when both the crops were grown in a fixed layout under four methods of tillage and crop establishment, *viz*. conventional tillage (CT)–raised-bed, CT–flat-bed, zero tillage (ZT)–raised-bed and ZT–flat-bed. This experimental set-up was used for growing soybean with the same treatments of tillage and crop establishment. Further, each main plot was split into four to accommodate weed management practices, *viz*. pendimethalin + hand weeding, pendimethalin + imazethapyr, wheat straw mulch + imazethapyr, and unweeded control. A split-plot design with 3 replications was followed, with each subplot measuring 6.0 × 2.8 m.

Ploughing was done with a disc-harrow followed by cultivator and rotavator in CT plots, while no soil disturbance was done in ZT plots. Soybean 'DS 9814' was sown in the second week of July using seed-cum-fertilizer drill under CT and ZT flat-bed conditions at 35 cm row spacing. In case of raised-bed (35 cm each of bed and furrow), sowing was done with bed-planter with two rows of soybean on the bed spaced at 26 cm. A seed rate of 80 kg/ha along with basal fertilizer dose of 20 kg N + 20.7 kg P + 30.8 kg K/ha was followed uniformly. A plant to plant spacing of 5-7 cm was maintained after thinning at 20 days after sowing (DAS). The crop was raised under irrigated conditions with one and three irrigations applied during 2010 and 2011, respectively. The crop matured in the first week of October.

Paraquat @ 1.0 kg/ha was sprayed in ZT plots one week before sowing. Pre-emergence application of pendimethalin @ 0.75 kg/ha was made within two days of sowing. Imazethapyr @ 75 g/ha was applied at 30 days of growth. Hand weeding was done at 30 DAS with help of hand-hoe. Wheat straw mulch was applied @ 5 t/ha after sowing.

Observations were recorded on weed species population and dry matter, and growth and yield parameters of soybean. The yields were recorded from net plot area of 8.4 m^2. Concentration of N, P and K in composite weed sample at 60 DAS, seed and stover of soybean at maturity were determined and the uptake values were calculated. Economic analysis was done based on the prevailing cost of inputs, field operations and price of produce. The biometric data were analyzed by standard statistical techniques, and treatment means were compared at P=0.05.

RESULTS AND DISCUSSION

Weed growth

Major weed flora in soybean field were: *Echinochloa colona* (11.5%) among grassy; *Digera arvensis* (11.4%) among broad-leaved; and *Cyperus rotundus* (62.5%) among sedges. Weed growth was not much different in the two years. In general, higher weed count was noticed under ZT than CT, and under flat-bed than raised-bed at 60 DAS (Table 1). Higher weed count under ZT conditions was due to presence of some of the previously growing weeds, mainly *Cyperus rotundus*, which was not fully controlled by paraquat applied before sowing. The foliage of this weed was desiccated due to paraquat but regenerated after two weeks. On other hand, all the weeds growing previously were killed due to tillage operation under CT, and emergence of new weeds was also delayed compared with crop seedlings. Lower weed population in the bed-planted crop was due to closer row spacing on the bed (26 cm) and greater spacing of the furrows (44 cm). More foliage growth of the bed-planted crop also checked weed population in the furrows. There was significant difference in weed dry weight at 60 DAS due to tillage and crop establishment practices. Weed dry weight was significantly higher under ZT-flat-beds compared with only CT–raised-bed because of no-tilling of the soil compared with 3 ploughings given under CT. Although there was greater weed infestation in the furrows initially due to more space and better soil moisture condition, the weeds in furrows got smothered with advancement of crop growth and development of canopy cover. On the other hand, flat-bed crop was sown at uniform spacing (35 cm), which provided adequate and uniform inter-row space for the weeds to grow. Several workers reported decrease in weed infestation in bed-planted compared with flat-sown crops (Chauhan *et al*., 2001; Singh *et al*., 2004; Mishra and Singh, 2009).

Weed management practices brought about significant effect on weed growth. Presumably, the highest weed count was under unweeded control, which was decreased by more than half due to different treatments (Table 1). Pre-emergence application of pendimethalin provided effective control of all species from early stages. Further, HW and post-emergence application of imazethapyr at 30 DAS checked the emergence of the second flush of weeds. Both of these treatments, i.e. pendimethalin + HW and pendimethalin + imazethapyr were equally effective and resulted in near weed-free conditions throughout. Application of wheat residue mulch after sowing checked the emergence of weeds to some extent and resulted in relatively better hydrothermal regime than non-mulched plots (Acharya and Sharma, 1994). In the mulched plots, the post-emergence application of imazethapyr controlled both grassy and broad-leaved weed species, and also showed suppressing effect on *Cyperus rotundus.* This indicates that application of wheat straw mulch, followed by post-emergence imazethapyr were equally good as pendimethalin + imazethapyr for reducing weed dry weight. Mean weed control efficiency was the lowest under ZT–flat, and was almost equal (79.5–82.5%) under different treatments of weed management.

Pendimethalin is the most popular herbicide for weed management in most crops including soybean. It is widely recommended for weed control without any adverse effect on crop growth. In this study too, pre-emergence application of pendimethalin provided complete elimination of annual grassy and broad-leaved weed species. Second flush of the weeds was checked by HW or application of imazethapyr at 30 DAS. Thereafter, there was no weed emergence due to development of adequate canopy cover, which suppressed late-emerged weeds. These results indicate that post-emergence application of imazethapyr was as good as HW in reducing weed growth (Jadhav and Gadade, 2012; Upadhyay *et al*., 2012). Mulching with wheat straw appeared to be more beneficial under ZT than CT condition. Retention of crop residue on soil surface is considered an essential component of conservation agriculture for controlling weeds and providing other beneficial effects on crop growth.

Interaction between tillage and crop establishment and weed management practices was significant. The results suggested that weed growth was lower under CT than ZT, particularly under unweeded conditions. There was considerable build-up of weed population under ZT when no control measures were adopted. In other words, employing chemical and cultural methods was more beneficial for reducing weed growth under ZT and CT condition. Sequential application of herbicides alone or integrated weed management involving pendimethalin + HW was more effective under both ZT and CT condition. Further, straw mulching proved essential for weed management, particularly under ZT condition.

Growth and yield parameters of soybean

Growth of soybean in terms of plant height and leaf area varied non-significantly, while dry matter accumula-

Table 1. Weed growth at 60 days after sowing of soybean as influenced by tillage and crop establishment, and weed management

Treatment	2010		2011		Mean weed control efficiency (%)
	Weed count (no./m^2)	Weed dry weight (g/m^2)	Weed count (no./m^2)	Weed dry weight (g/m^2)	
Tillage and crop establishment					
CT – raised-bed	7.74 (63.4)	111.3	7.96 (66.8)	113.4	60.9
CT – flat-bed	7.83 (63.5)	115.8	8.64 (77.3)	116.6	62.1
ZT – raised-bed	8.05 (67.1)	119.3	8.50 (74.7)	122.7	60.3
ZT – flat-bed	9.09 (88.4)	123.2	8.99 (84.2)	125.5	58.7
SEm±	0.19	2.73	0.10	2.77	
CD (P=0.05)	0.66	9.47	0.35	9.61	
Weed management					
Unweeded control	11.29 (128.5)	277.7	11.63 (134.9)	330.8	0.0
Pendimethalin + HW	6.88 (48.3)	57.8	6.90 (47.6)	44.6	82.5
Pendimethalin + imazethapyr	7.17 (51.5)	65.2	8.13 (65.8)	53.3	79.9
Wheat straw mulch + imazethapyr	7.37 (54.1)	68.9	7.43 (54.7)	49.5	79.5
SEm±	0.20	1.96	0.11	2.27	
CD (P=0.05)	0.59	5.71	0.33	6.64	

*Data given within parentheses are original values, which were transformed $\sqrt{x \pm 0.5}$ for rational analysis tion was significant due to tillage and crop establishment (Table 2). Dry matter production was invariably higher under CT than ZT condition, and was comparatively lower under flat-bed than raised-bed sown crop. The CT–raised-bed maintained its superiority from early growth stages and recorded significantly higher dry matter than other treatments. Growth parameters were improved significantly with weed management over unweeded conditions. The increase in dry matter production was maximum with pendimethalin + HW, which was significantly more than all other treatments in 2010 but on par with pendimethalin + imazethapyr and wheat straw mulch + imazethapyr in 2011.

Yield attributes, *viz.* number of pods/plant, seeds/pod and 1000-seed weight were significantly influenced due to tillage and crop establishment, and weed management practices (Table 3). These attributes were comparatively more in 2011 than 2010. In general, these attributes were higher under CT than ZT, and under raised-bed than flat-bed conditions. The highest yield attributes were recorded under CT–raised-bed, which were on par with CT–flat-bed and ZT–raised-bed. ZT–flat-bed gave the lowest value of these attributes. The number of pods/plant was 27.3% more in 2011 compared to 2010. Number of seeds/pod was maximum under CT–raised-bed, which was on par with CT–flat-bed and ZT–raised-bed. Zero tillage–flat-bed resulted in significantly lower seeds/pod than CT-raised-bed, CT–flat-bed and ZT-raised-bed in both cropping cycles. In general, the lower number of seeds/pod under ZT–flat-bed was associated with lower number of pods/plant. A similar trend was observed in case of 1000-seed weight.

Yield attributes showed a significant improvement with weed management. Number of pods/plant, seeds/pod and 1000-seed weight were the highest with pendimethalin + HW in both years. Application of pendimethalin + imazethapyr also resulted in equal pods/plant and 1000-seed weight but seeds/pod were significantly lower in 2011. Wheat straw + imazethapyr recorded relatively lower values of these attributes compared with other treatments.

Seed and stover yield

Yield performance of soybean was comparatively better in 2011 than 2010 due to less rainfall, leading to better expression of growth and yield parameters (Table 3). Seed yield was significantly influenced by tillage and crop establishment but the differences in stover yield were not significant in both years of experimentation. Seed yield was the highest under CT–raised-bed, which was on par with CT–flat and ZT–raised bed. The lowest seed yield was under ZT–flat-bed, which was significantly lower than CT raised-bed. The highest harvest index was also recorded under CT condition in both methods of sowing. These results indicate that CT did not have any effect on yield of soybean under both methods of establishment but the flat-bed crop performed poorly under ZT. Heavy rainfall caused temporary waterlogging, resulting in better performance of raised-bed planting than flat-sown crop (Chauhan *et al*., 2001; Singh *et al*., 2004).

Weed management brought about large increases in crop productivity when weeds were controlled effectively by chemical and cultural means. Favourable environment was created within the crop canopy, which led to higher growth and yield attributes, and thereby yield performance. All three weed control practices, *viz.* pendimethalin + HW, pendimethalin + imazethapyr and wheat straw mulch + imazethapyr resulted in almost simi-

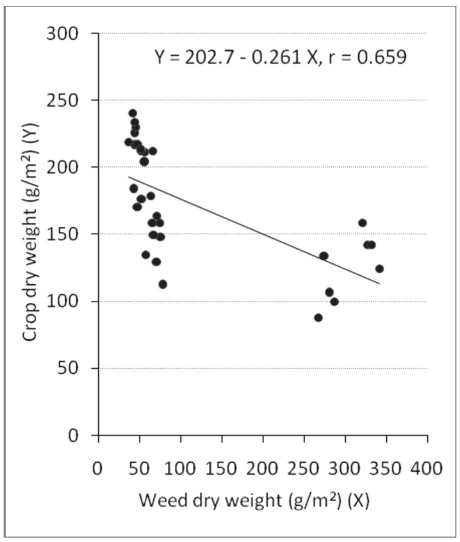
Table 2. Growth parameters of soybean as influenced by tillage and crop establishment, and weed management

Treatment	Plant height at maturity (cm)		LAI at 60 DAS		Dry matter accumulation at 60 DAS (g/m^2)	
	2010	2011	2010	2011	2010	2011
Tillage and crop establishment						
CT – raised-bed	73.2	82.7	6.88	7.53	160.7	213.6
CT – flat-bed	72.4	81.7	6.58	7.52	142.3	197.3
ZT – raised bed	72.5	81.2	6.78	7.49	148.3	201.6
ZT – flat-bed	70.6	78.8	6.50	7.43	122.0	188.6
SEm±	1.17	1.52	0.18	0.20	2.72	4.30
CD (P=0.05)	NS	NS	NS	NS	9.43	14.86
Weed management						
Unweeded control	68.3	69.3	5.04	5.59	107.0	141.7
Pendimethalin + HW	74.5	85.8	7.47	8.65	167.9	222.7
Pendimethalin + imazethapyr	73.1	83.4	7.06	7.81	154.8	215.9
Wheat straw mulch + imazethapyr	72.9	85.8	7.18	7.91	143.5	220.6
SEm±	0.79	0.84	0.13	0.14	1.69	2.77
CD (P=0.05)	2.30	2.45	0.39	0.40	4.92	8.10

lar weed control; thus gave equal seed and stover yield, which was significantly higher than unweeded control. The mean increase in seed yield under these treatments was 39.1 and 42.7% in 2010 and in 2011, respectively. The loss of seed yield in unweeded control was 38.3% and in 2010 and 40.1% in 2011. There was similar trend of variation in stover yield, and accordingly the harvest index showed significant improvement under weed control treatments compared with unweeded control. Mishra and Singh (2009) and Monsefi (2009) also found a similar response with the application of pendimethalin + HW at 20-30 DAS.

Interaction between tillage and crop establishment, and weed management practices on seed and stover yield of soybean was not significant. This indicated that the effect of weed management was similar under tillage and crop establishment and *vice-versa*. Unweeded control gave the lowest yield under all tillage and crop establishment practices. In other words, tillage and crop establishment practices alone did not provide effective weed control, and supplementation with weed management involving chemical and cultural methods was essential.

There was a significant negative correlation between weed and crop dry weight (Fig. 1). The crop dry weight decreased by 0.26 g/m^2 with unit increase in weed dry weight. Similarly, mean seed yield decreased by 0.002 t/ha



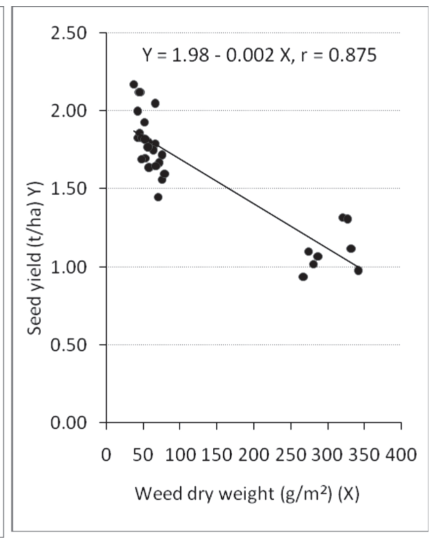


Fig. 1. Relationship between weed and crop dry weight, and seed yield (based on mean of two years

Table 3. Yield performance of soybean as influenced by tillage and crop establishment, and weed management

Treatment	2010					2011				
	Pods/ plant	Seeds/ pod	1000-seed weight (g)	Seed yield (t/ha)	Stover yield (t/ha)	Pods/ plant	Seeds/ pod	1,000-seed weight (g)	Seed yield (t/ha)	Stover yield (t/ha)
Tillage and crop establishment										
CT – raised-bed	43.5	1.90	135.8	1.59	3.35	59.8	1.97	142.1	1.89	3.66
CT – flat-bed	42.1	1.75	131.8	1.52	3.17	56.6	1.86	138.2	1.79	3.46
ZT – raised bed	42.7	1.84	131.5	1.55	3.40	56.6	1.90	139.3	1.78	3.47
ZT – flat-bed	36.4	1.62	125.9	1.39	3.16	50.0	1.79	135.6	1.63	3.43
SEm±	1.09	0.05	1.35	0.04	0.13	1.33	0.03	0.89	0.05	0.13
CD (P=0.05)	3.79	0.19	4.66	0.12	NS	4.62	0.11	3.07	0.17	NS
Weed management										
Unweeded control	30.3	1.47	125.6	1.03	2.60	29.5	1.22	122.2	1.18	2.79
Pendimethalin + HW	46.4	1.95	133.7	1.71	3.61	66.3	2.20	145.5	2.06	3.89
Pendimethalin + imazethapyr	44.7	1.91	132.2	1.62	3.49	63.9	2.07	144.3	1.95	3.64
Wheat straw mulch + imazethapyr	43.2	1.78	133.6	1.68	3.37	63.3	2.03	143.1	1.89	3.70
SEm±	0.85	0.05	0.80	0.02	0.10	1.02	0.02	0.76	0.04	0.06
CD (P=0.05)	2.49	0.13	2.33	0.07	0.28	2.97	0.07	2.21	0.12	0.19

with unit increase in weed dry weight. At weed dry weight of < 50 g/m^2, the crop biomass and seed yield appeared to be maximum, which could be considered as the threshold level. Beyond this, for every increase of 100 g/m^2 of weed dry weight, the crop biomass and seed yield decreased by 26.1 g/m^2 and 0.2 t/ha, respectively.

Nutrient concentration and uptake

Concentration of N, P and K in seed and stover of soybean was not influenced due to tillage and crop establishment. Similarly, there was no significant effect when weeds were effectively controlled. However, the uptake of nutrients was significantly different under tillage and weed management practices (Table 4). The uptake values increased due to higher biomass production under different treatments. The nutrient uptake was the highest under CT–raised-bed and on par with ZT–raised-bed, while the lowest value was observed under ZT–flat-bed. The treatments, *viz.* CT–flat-bed and ZT–raised-bed resulted in intermediate nutrient uptake. These results indicated that better crop growth following reduced weed infestation under raised-bed, irrespective of tillage, provided adequate supply of nutrients to the crop plants, leading to higher nutrient uptake.

Weed management practices caused large and significant differences in nutrient uptake. The uptake of N and K was maximum under pendimethalin + HW, which was significantly more than pendimethalin + imazethapyr and wheat straw mulch + imazethapyr. However, all these three treatments were significantly superior to unweeded control. The decrease in uptake of N, P and K under unweeded control was to extent of 30.2-37.0%. These variations were evident from the fact that the weeds removed large quantity of nutrients under unweeded control, while under other weed management treatments, the nutrients available in soil were effectively utilized by crop plants for growth and development. Therefore, controlling weeds not only helped in improving yield but also nutrient uptake by increasing nutrient concentration in seed and stover of soybean.

The concentration of nutrients in weeds was not influenced due to tillage and crop establishment, and weed management practices. However, there was significant difference in nutrient removal by weeds due to the variation in biomass production (Table 4). The uptake of K was the highest, followed by N and P. Evidently, the removal of N, P and K by weeds followed a trend opposite to nutrient uptake by soybean. In other words, the treatments which resulted in higher nutrient uptake by crop, led to lower nutrient removal by weeds, and *vice-versa*. Accordingly, the nutrient removal by weeds was the highest under ZT–flat-bed and the lowest under CT–raised-bed.

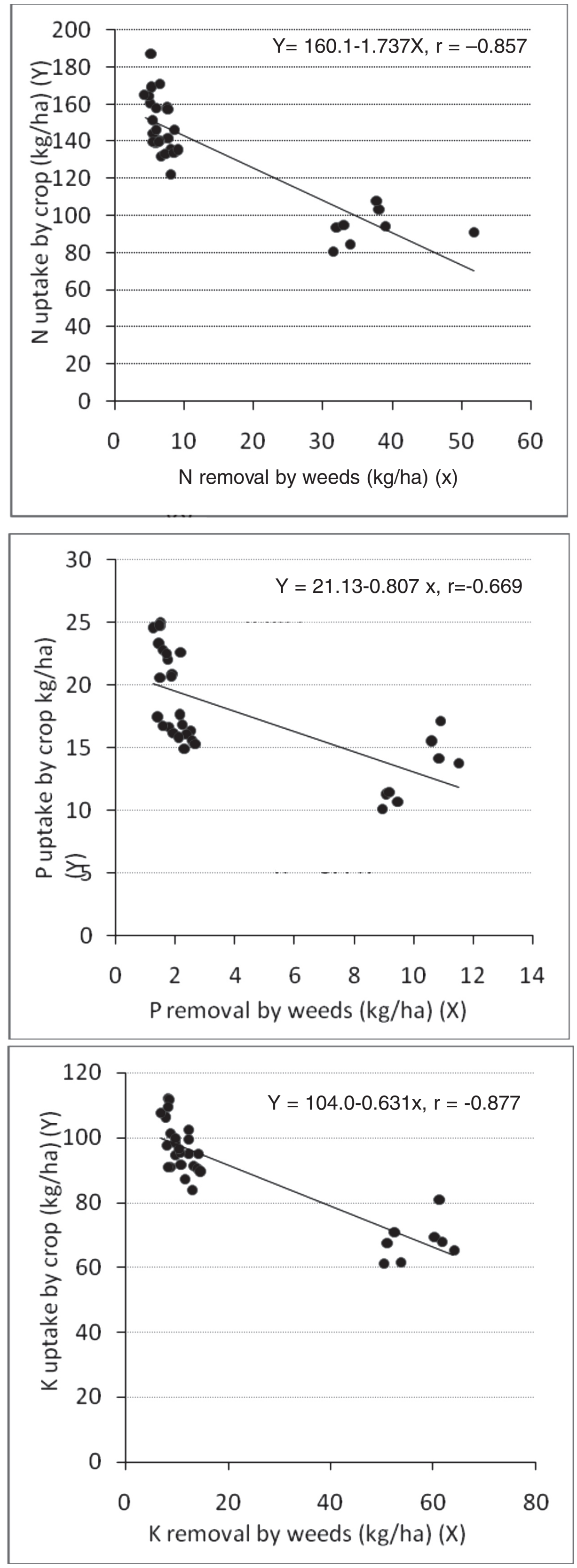


Fig. 2. Relationship between nutrient removal by weeds and crop uptake (mean of two years)

Unweeded control resulted in the highest removal of nutrients by weeds, which was decreased significantly under different weed control treatments. The lowest nutrient removal was with pendimethalin + HW, which was on par when compared with pendimethalin + imazethapyr and wheat straw mulch + imazethapyr for N but significantly lower for P and K. The decrease in nutrient uptake under these treatments compared with unweeded control was to the extent of 81.3–82.1%. Therefore, it was essential to control weeds to decrease nutrient losses, and accordingly, increase the nutrient availability to the crop.

Nutrient uptake by soybean and weeds followed opposite trends, i.e. the treatments which caused higher nutrient uptake by soybean resulted in reduced nutrient re-

Table 4. Nutrient uptake (kg/ha) by soybean at harvest and by weeds at 60 days of growth as influenced by tillage and crop establishment, and weed management (mean of two years)

Treatment	Soybean			Weeds		
	N	P	K	N	P	K
Tillage and crop establishment						
CT – raised-bed	145.7	18.8	94.1	13.2	3.73	21.0
CT – flat-bed	131.3	17.9	88.7	13.6	3.88	21.7
ZT – raised bed	137.9	18.3	91.7	14.4	3.98	22.5
ZT – flat-bed	126.0	16.9	85.6	16.0	4.17	23.3
SEm±	2.42	0.38	1.42	0.3	0.084	0.49
CD (P=0.05)	8.22	1.21	4.83	1.16	0.285	1.66
Weed management						
Unweeded control	93.9	13.0	68.0	37.2	10.07	56.8
Pendimethalin + HW	158.4	20.5	101.0	6.19	1.72	9.6
Pendimethalin + imazethapyr	143.3	19.2	95.4	6.93	1.98	11.1
Wheat straw mulch + imazethapyr	145.4	19.2	95.7	6.90	1.99	11.0
SEm±	1.74	0.32	1.19	0.29	0.068	0.36
CD (P=0.05)	5.06	0.93	3.46	0.86	0.197	1.04

Table 5. Economic analysis of soybean cultivation as influenced by tillage and crop establishment, and weed management

Treatment	Cost of cultivation ($\times 10^3$₹/ha)		Net returns ($\times 10^3$₹/ha)		Net B:C ratio	
	2010	2011	2010	2011	2010	2011
CT - raised-bed						
Unweeded control	12.32	12.32	11.07	15.32	0.90	1.24
Pendimethalin + HW	16.50	16.50	21.83	27.85	1.32	1.69
Pendimethalin + imazethapyr	15.40	15.40	20.46	29.02	1.33	1.88
Wheat straw mulch + imazethapyr	16.72	16.72	19.56	25.17	1.17	1.51
CT - flat-bed						
Unweeded control	12.02	12.02	10.54	15.86	0.88	1.32
Pendimethalin + HW	16.20	16.20	19.29	25.05	1.19	1.54
Pendimethalin + imazethapyr	15.10	15.10	20.04	23.70	1.33	1.57
Wheat straw mulch + imazethapyr	16.42	16.42	18.10	21.40	1.10	1.30
ZT - raised-bed						
Unweeded control	11.20	11.20	10.66	12.57	0.95	1.12
Pendimethalin + HW	15.37	15.37	22.31	28.98	1.45	1.88
Pendimethalin + imazethapyr	14.27	14.27	20.62	28.50	1.44	2.00
Wheat straw mulch + imazethapyr	15.60	15.60	20.86	22.97	1.34	1.47
ZT - flat-bed						
Unweeded control	10.90	10.90	9.16	10.14	0.84	0.93
Pendimethalin + HW	15.07	15.07	17.79	23.18	1.18	1.54
Pendimethalin + imazethapyr	13.97	13.97	16.72	23.23	1.20	1.66
Wheat straw mulch + imazethapyr	15.30	15.30	18.44	25.07	1.21	1.64

Cost of cultivation (₹/ha): common cost – 9475, treatment cost: CT – 1000, flat-bed – 750, raised-bed – 1050, hand weeding – 3000, pendimethalin – 875, imazethapyr – 1600, paraquat – 375, herbicide spray – 300, wheat straw – 2500
Price of output (₹/t): seed – 20,000; stover – 500

moval by weeds, and *vice-versa*. Regression analysis indicated that crop uptake of nutrients decreased linearly with increase in nutrient removal by weeds (Fig. 2). The uptake of N, P and K of soybean decreased by a magnitude of 1.74, 0.81 and 0.63 kg, respectively with unit increase in removal of these nutrients by weeds. This indicates that loss was more for N than other nutrients, and the nutrient uptake of crop can be increased by deceasing nutrient removal by weeds. Crop and weeds compete for nutrients, and the weeds being more vigorous than the crop, their effective control should be ensured from early stages.

Economics

Total cost of cultivation varied among different treatments due to variation in cost of tillage and methods of establishment, and weed management (Table 5). Evidently, the total cost was the highest under CT–raised-bed and the lowest under ZT–flat-bed. Among the weed control treatments, the cost was the highest under wheat straw mulch + imazethapyr. Herbicide application was much cheaper than manual weeding, while wheat straw being an equally important byproduct as grain, added to the cost. Net returns followed the trend of seed and stover production, and were more in 2011 than 2010 due to relatively higher yields obtained. When the weeds were not controlled, CT was a better practice, but controlling weeds led to about two-times increase in net returns than unweeded control. The net returns were the highest under raised-bed and pendimethalin + HW, followed by pendimethalin + imazethapyr, irrespective of tillage. Net B : C ratio was the highest under ZT-raised-bed and pendimethalin + imazethapyr or pendimethalin + HW in both years. The net B : C ratio decreased under wheat straw mulch + imazethapyr, particularly due to relatively lower yields under this treatment and inclusion of cost of wheat straw. However, application of crop residue might prove beneficial in the long-run due to several indirect benefits, such as improvement in physico-chemical and biological properties of the soil.

It was concluded that productivity and profitability of soybean could be increased by adopting ZT and raised-bed method of establishment. Effective control of weeds was achieved by pre-emergence application of pendimethalin, followed by either HW or imazethapyr as post-emergence. Although wheat straw mulching was effective in improving weed control and crop productivity, it was less economical in the short-term due to higher cost of wheat straw. Nonetheless, ZT + crop residue along with adequate weed control through chemical means alone or integrated weed management might prove beneficial in the long-run.

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