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Review/Overview

Carry-over effect of weed management practices of maize (*Zea mays*) on weed dynamics and productivity of succeeding zero and conventional till wheat (*Triticum aestivum*)

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ABSTRACT

Effective weed control in no-till systems is mainly based on herbicides. Appropriate weed management strategies can reduce the application of herbicides to a considerable extent. In the study, a possible weed management has been envisaged in zero-till (ZT) with and without residue, and conventional till (CT) wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] during 2010-11 and 2011-12 at Indian Agricultural Research Institute, New Delhi following residual effects of 12 weed control treatments, comprising of tank-mix and sequential application of herbicides in the previous rainy (*kharif*) seasons, 2010 and 2011 in maize (*Zea mays* L.). It was observed that total density of weeds did not differ significantly between weed control treatments adopted during previous rainy seasons. But, ZT with maize residue retention (ZT+R) caused a significant reduction on the population of grasses (e.g. *Phalaris minor, Avena ludoviciana*), broad-leaved (e.g. *Chenopodium album*, *Melilotus indica*) and total weeds compared to CT and ZT (without residue). Wheat yield was almost similar in all previous season tank-mix and sequential herbicide applications except that in weed-free check adopted during both the seasons in both years. But, the tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha combined with ZT+R resulted in higher wheat yield, and was comparable with weed-free check, indicating its considerable residual effect on weeds in wheat. This tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha when followed by ZT in wheat fetched higher net returns and net benefit:cost, which showed its superiority over other weed control treatments except weed-free check.

Key words: Maize, Productivity, Tillage, Weed dynamics, Weed management, Wheat

Maize has wide adaptability and compatibility under diverse soil and climatic conditions. It is cultivated in sequence with different crops under various agro-climatic regions of the country. Hence, it is considered as one of the potential driver of crop diversification under different situations. Among different maize- based cropping systems, maize-wheat ranks first (Jat *et al*., 2011). Minimum tillage systems are adopted worldwide because of savings in time and economic inputs. However, as tillage is reduced, weed control can become a limiting factor in crop production. Moreover, changes in tillage practices can affect weed population dynamics, including weed seed distribution and abundance in soil seed bank (Mulugeta and Stoltenberg, 1997). Tillage also reduces number and diversity of weed species, but increases germination of annual weed seeds in the soil seed bank. Thus, in no-till systems, weed control is largely dependent on herbicides, and appropriate use of herbicides is more important than in traditional tillage systems mainly in years with a high yield potential (Young *et al*., 1994). In sub-tropical climate, winter cereals including wheat are often sown at a time when initial emergence potential of many weeds is not reached due to delay of rainy season, and irregular or no rainfall during winter. Zero till wheat is being introduced to avoid late planting and poor land preparation. It ensures timely planting, better stand establishment and higher grain yield than conventional method. It also saves 30% on irrigation and land preparation costs (Zamir *et al*., 2010). However, previous crops, as well as weed infestation and weed control measures can alter the direct effect of ZT on wheat yield. Hence, the suitability and benefits of chemical weed control in maize must be evaluated in a crop rotation with wheat. Results on the concurrent effects of herbicides in maize and their residual effect in combi-

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nation with ZT on weeds in wheat would be of paramount importance towards weed management in maize-wheat cropping system. In no-till systems, seeds of weeds and volunteer crops are frequently deposited in the first few centimeters of top soil. Despite the mentioned restrictions for weed development in no-till systems, it is essential to control weeds before direct sowing in order to minimize crop yield losses in these systems. An appropriate strategy, therefore, is needed to avoid high weed infestations and to prevent unacceptable competition with crop. Herbicide research should be cropping system-based. Cultivars of several crops including winter wheat differ considerably in their tolerance to herbicides like atrazine, pendimethalin, imazethapyr and chlorimuron. Residual toxicity of herbicides on the succeeding crops is one of the main considerations in the use of chemicals for weed control. Singh and Rao (1974) reported that the principle involved in the bioassay is the phytotoxicity of chemical in the soil as reflected on germination, vegetative production and growth of the indicator plants. Studying residual effect of these herbicides applied to maize on succeeding wheat assumes relevance. Thus, the objective of this study was to verify residual effect of tank –mix and sequential application of herbicides applied to preceding maize on wheat and to find out the economics of wheat cultivation under such system.

MATERIALS AND METHODS

A field experiment was carried out during the *rabi* seasons of 2010-11 and 2011-12 at the Indian Agricultural Research Institute, New Delhi, on plots applied with 12 weed control treatments (Table 1) in the preceding *kharif* season maize superimposed with conventional till (CT) and zero till (ZT) systems (with and without residue) during winter in wheat. Soil was sandy loam, pH 7.6, organic C (0.52%), medium in available nitrogen (272.6 kg/ha), medium in phosphorus (18.4 kg/ha) and potassium (191.6 kg/ha). In *kharif* season, maize crop was grown with the stipulated treatments and the effect of these treatments was studied in *rabi* season wheat. Maize crop performed well in rainy season and gave satisfactory yield. All the treatments except weed-free check were disturbed in wheat just to find out the residual effect of the *kharif* season treatments. In weed-free check, the plots were maintained free of weeds through manual weeding as and when required. A pre-sowing irrigation was given to entire field to facilitate smooth germination of wheat. Conventional tillage plots were ploughed by a tractor-drawn disc plough followed by planking. Previous season maize residue was retained on zero-tillage (ZT) with residue plots and ZT without residue plot was left undisturbed. Wheat 'PBW 550' was sown by a seed drill with a spacing 22.5 cm between rows with a 100 kg/ha seed rate. A dose of 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha was applied to wheat. Nitrogen was applied in two splits; half at sowing and the remaining half at the time of first irrigation 21 DAS at crown root initiation (CRI) stage. Nitrogen, phosphorus and potassium were applied in the forms of urea, single superphosphate and muriate of potash, respectively. An area of 0.25 m^2 was selected randomly at two spots by throwing a quadrat of 0.5 m x 0.5 m, weed species were counted from that area, and density was expressed in number per m^2. The collected weeds were first sun-dried and then kept in an electric oven at 70^0C till the weight became constant, and dry weight was expressed as g/m^2. The population and dry weight of weeds were transformed through square-root [$\sqrt{(x+0.5)}$] method before analysis of variance. Weed control efficiency (WCE) based on weed population, and weed control index (WCI) based on weed dry weight were determined from pooled weed population and dry weight, respectively. Data on wheat grain yield were recorded from the net plot, whereas yield attributes from five randomly selected plants at harvest. Cost of cultivation and gross and net returns were calculated based on the prevailing prices of inputs and outputs. Net benefit:cost (Net B:C) was calculated on the basis of net returns divided by the cost of cultivation.

RESULTS AND DISCUSSION

Weed population and dry weight

Dominant weed flora in wheat comprised of *Chenopodium album* L., *Melilotus indica* L. among broad-leaved weeds; *Phalaris minor* Retz., *Avena sterilis* ssp *ludoviciana* (Dur.) Nym. among grasses; and *Cyperus rotundus* among sedges. With regard to the residual effect of previous season weed control measures with tank-mix and sequential herbicide applications, it was observed that almost all these treatments significantly reduced total weed population compared to weedy check (Table 1). These treatments were more or less comparable with each other on their effect on weed population (Table 1) and dry weight (Table 2) and these treatments significantly decreased total number and dry weights of weeds compared with weedy check at 60 DAS during both years. Zero-tillage with maize residue retention resulted in a significant reduction in the populations (Table 1) and dry weights (Table 2) of *Chenopodium album, Melilotus indica* and grasses compared to zero-tillage without residue at 60 DAS (Table 1). In this study, grasses (*Phalaris minor*, *Avena sterilis* ssp *ludoviciana)* and *Chenopodium album* were more, compared to *Melilotus indica* (Tables 1). Highest density of *Chenopodium album* was observed in weedy check. *Chenopodium album* has naturalized in the field since long time and usually occurs in large population every year. Rainy-season tank-mix pre-emergence and sequential herbicide applications reduced the populations of *Chenopodium* and *Melilotus*. This indicated possible residual effect of previous season weed control/ herbicide treatments on these weeds. In fact, the residual effects of the previous season weed control treatments were imminent, which resulted in 20.8–32.1% WCE (Table 1). Similarly, the weed control index (WCI) varied from 21.9–41.8% in these treatments (Table 2). The broad-spectrum activity and persistence nature of these herbicides might have played a role. The use of herbicide imazethapyr as well as its tank-mix with pendimethalin in novel in maize crop in the world. Hardly any work on these aspects is reported elsewhere. However, being two years data, it reflects on the authenticity of results. However, possible reason could be that these might have reduced their seed-bank upon application during *kharif* season. Besides, their effects have been compounded with treatments during *rabi* season. Residual effect of these treatments was negligible on grasses. Control of weeds before crop establishment in a no-till system decreases substantially the potential infestation during crop development as it minimizes soil disturbance, which has a positive effect on weed emergence. Such results might have accentuated from considerable reductions in the populations (Table 1) and dry weights (Table 2) of *Chenopodium album* and *Melilotus indica* in these treatments compared to that of weedy check. Weed free check due to having both season weed removal resulted in highest WCE (Table 1) and WCI (Table 2).

Some of the weeds infesting this cropping system are present in much greater density under the conventional system. This may be due to the higher soil disturbance

Table 1. Effect of previous season weed control measures supplemented with CT and ZT with and without residue on weed density in wheat at 60 DAS and weed control efficiency (WCE) (mean of 2 years)

Treatment		*Chenopodium album* (No./m²)	*Melilotus indica* (No./m²)	Grasses** (No./m²)	Total weed density (No./m²)	WCE (%)
Weed control treatment during previous rainy-season						
T_1 :	Weedy check	9.6 (92.95)	5.7 (33.15)	11.9 (141.75)	16.35 (267.85)	0
T_2 :	Atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha (tank-mix PE)	7.1 (51.55)	3.85 (15.75)	9.7 (99.55)	12.95 (166.95)	20.8
T_3 :	Atrazine 1.0 kg/ha + hand weeding at 30 DAS	6 (39.55)	3.85 (15.35)	9.65 (94.65)	12.25 (149.55)	25.1
T_4 :	Atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha	6.35 (42.75)	3.9 (15.75)	9.8 (95.95)	12.45 (154.45)	23.8
T_5 :	Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	5.55 (33.35)	2.9 (9.55)	9.05 (79.55)	11.1 (122.45)	32.1
T_6 :	*KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	5.95 (36.45)	3 (9.55)	8.85 (81.35)	11.3 (127.35)	30.9
T_7 :	Pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE)	6 (37.85)	2.75 (9.15)	9.1 (83.95)	11.45 (130.95)	29.9
T_8 :	Pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand	6 (39.55)	3.75 (14.85)	9.3 (88.45)	11.95 (142.85)	26.9
T_9 :	Pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand	6.05 (40.05)	3.75 (14.45)	9.35 (88.85)	11.95 (143.35)	26.9
T_{10} :	Brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	7.25 (57.35)	4.4 (19.35)	10.95 (119.55)	13.8 (185.55)	15.6
T_{11} :	Brown manuring (*Sesbania* @ 10 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	7.35 (53.85)	4.25 (18.85)	10.6 (113.35)	13.9 (192.65)	15.0
T_{12} :	Weed-free check	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	95.7
	SEm ±	1.39	0.42	0.41	0.35	-
	LSD (P=0.05)	0.56	1.25	1.19	1.03	-
Tillage level during winter						
	CT	6.1 (40.15)	3.55 (13.65)	9.55 (94.8)	12.25 (148.6)	0
	ZT + R	4.9 (27.15)	2.95 (9.65)	7.5 (59.5)	9.85 (96.3)	19.6
	ZT	7.5 (59.85)	4.65 (22.85)	10.7 (117.3)	14.2 (199.9)	-15.9
	SEm±	0.75	0.15	0.17	0.22	-
	CD (P=0.05)	2.14	0.44	0.48	0.64	-

** Grasses include *Phalaris minor* and *Avena sterilis* ssp *ludoviciana*; Data were transformed through square-root ($\sqrt{(x+0.5)}$) method; Figures in the parentheses are original values under conventional systems. In no-till systems, the occurrence of perennial weeds is more, and changes in the temperature and light incidence on the soil surface influence dormancy of some weed species. The weed suppressive effects of maize crop residue have resulted in greater reduction of weeds in zero-tillage with residue (Christoffoleti *et al*., 2007). No-till with crop residue management is an important multi-tactic approach to manage weed population dynamics in crop rotations. Retention of crop residue on the soil surface under no-till systems can suppress weed seedling emergence, delay the time of emergence, and allow the crop to gain an advantage over weeds, and reduce the need for control.

Yield attributes and yield of wheat

Due to greater suppression of weeds compared to weedy check, the negative effect of weeds on ear bearing tillers, wheat grains/ear, 1,000-grains weight and yield was reduced in the pre-emergence, tank-mix and sequential application of herbicides treatments applied to previous maize crop (Table 3). The differences were significant with regard to number of wheat grains/ear, 1000-grains weight and biological yield (Table 3). Wheat yield (Table 4) differed significantly between previous season weed control measures and tillage treatments in both the years. But there was no significant interaction between the previous season weed control measures and tillage treatments in both the cases. However, weed-free check was comparable with application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE) (T_5) and resulted in significantly higher yield than others (Table 4).

The grain yield of wheat and yield attributes differed significantly due to tillage and weed control measures. ZT with maize residue retention had significantly higher number of ear bearing tillers, wheat grains/ear and 1000-grain weight compared to CT and zero-tillage without residue

Table 2. Weed dry weight (g/m^2) in wheat at 60 DAS as affected by previous season weed control measures supplemented with conventional and zero tilled (with and without residue) during winter (mean of 2 years)

Treatment (g/m^2)	*Broad leaved** (g/m^2)	Grasses** (g/m^2)	Total (%)	WCI
Weed control treatment during rainy-season				
T_1 : Weedy check	5.85 (34.15)	6.95 (48.1)	12.8 (82.25)	0
T_2 : Atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha (tank-mix PE)	4.75 (23.05)	5.25 (29.1)	10 (52.15)	21.9
T_3 : Atrazine 1.0 kg/ha + hand weeding at 30 DAS	4.45 (21.95)	4.75 (23.4)	9.2 (45.35)	28.1
T_4 : Atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha	4.15 (19.75)	4.8 (23.7)	8.95 (43.45)	30.1
T_5 : Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	3.9 (15.15)	3.55 (12.7)	7.45 (27.85)	41.8
T_6 : *KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	4.1 (16.35)	4.05 (16.5)	8.15 (32.85)	36.3
T_7 : Pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE)	4 (16.75)	4.55 (22.1)	8.55 (38.85)	33.2
T_8 : Pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand	4.3 (18.35)	4.9 (24.8)	9.2 (43.15)	28.1
T_9 : Pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand	4.2 (19.25)	4.8 (23.1)	9 (42.35)	29.7
T_{10} : Brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	5.2 (27.45)	5.6 (31.8)	10.8 (59.25)	15.6
T_{11} : Brown manuring (*Sesbania* @ 10 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	4.85 (24.85)	5.55 (31.8)	10.4 (56.25)	18.7
T_{12} : Weed-free check	0.7 (0.0)	0.7 (0.0)	1.4 (0.0)	89.1
SEm±	0.41	0.45	0.86	-
CD (P=0.05)	1.20	1.34	2.55	-
Tillage level during winter				
CT	4.05 (17.55)	5.35 (30.3)	9.4 (47.85)	0
ZT + R	3.45 (12.25)	4.05 (17.2)	7.5 (29.45)	20.2
ZT	5.4 (30.95)	4.85 (24.4)	10.25 (55.35)	- 9.0
SEm±	0.165	0.205	0.37	-
CD (P=0.05)	0.47	0.47	0.94	

* Broad leaved weeds include *Chenopodium album, Melilotus indica, Fumaria indica, Spergula arvensis* and *Anagallis arvensis;* ** Grasses include *Phalaris minor* and *Avena sterilis* ssp *ludoviciana*; Data were transformed through square-root method; Figures in the parentheses are original values.

resulting in higher grain yield. The differences with regard to number of wheat grains/ear, 1000-grains weight, grain yield and biological yield were significant. This was, probably, due to compensatory effects between yield components during growth and development of crop, and to a lower number of weeds/m^2 (broad-leaved, grasses and total) at heading stage of wheat. A significant effect on wheat yield was observed in both the years, and weed-free check being comparable with application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE) (T_5),

Table 3. Grains/ear, 1,000-grain weight and biological yield of wheat as affected by previous season weed control measures supplemented with or without tillage during winter (mean of 2 years)

Treatment	Grains/ear	1,000-grains weight (g)	Biological yield (t/ha)
Weed control treatment during rainy-season			
T_1 : Weedy check	30.5	37.3	8.71
T_2 : Atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha (tank-mix PE)	36.4	37.7	9.28
T_3 : Atrazine 1.0 kg/ha + hand weeding at 30 DAS	36.7	37.8	9.32
T_4 : Atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha	37.1	38.1	9.40
T_5 : Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	40.4	40.4	9.91
T_6 : *KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	38.4	39.0	9.56
T_7 : Pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE)	35.3	37.6	9.06
T_8 : Pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand	37.5	38.2	9.53
T_9 : Pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand	36.7	37.8	9.29
T_{10} : Brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	35.9	37.7	9.23
T_{11} : Brown manuring (*Sesbania* @ 10 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	35.3	37.6	9.17
T_{12} : Weed-free check	42.4	41.3	10.35
SEm±	0.14	0.02	0.08
CD (P=0.05)	0.40	0.06	0.22
CT	37.3	38.6	9.27
ZT + R	37.9	38.6	9.70
ZT	35.6	37.6	9.23
SEm±	0.15	0.13	0.06
CD (P=0.05)	0.42	0.36	0.18

*KNO_3 was applied separately; PE –pre-emergence; POE - post emergence

Table 4. Grain yield of wheat (t/ha) as affected by previous season weed control measures supplemented with or without tillage during winter (mean of 2 years)

Treatment	Tillage level during winter			
	CT	ZT+R	ZT	Mean
Weed control treatment during rainy-season				
T_1 : Weedy check	3.06	3.12	3.03	3.07
T_2 : Atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha (tank-mix PE)	3.23	3.77	3.23	3.41
T_3 : Atrazine 1.0 kg/ha + hand weeding at 30 DAS	3.59	3.91	3.44	3.65
T_4 : Atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha	3.64	3.95	3.49	3.69
T_5 : Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	4.16	4.48	4.01	4.22
T_6 : KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE)	3.93	4.24	3.78	3.99
T_7 : Pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE)	3.15	3.24	3.07	3.15
T_8 : Pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand	3.62	3.94	3.48	3.68
T_9 : Pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand	3.56	3.88	3.41	3.62
T_{10} : Brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	3.13	3.68	3.14	3.31
T_{11} : Brown manuring (*Sesbania* @ 10 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS)	3.11	3.66	3.12	3.29
T_{12} : Weed-free check	4.22	4.56	4.12	4.3
Mean (Tillage)	3.53	3.87	3.44	
Mean (Years)				
H	T	Y	H×Y	
SEm±	0.04	0.02	0.01	0.06
CD (P=0.05)	0.10	0.05	0.04	0.17

*KNO_3 was applied separately; H, herbicide; T, Tillage; Y, year

resulted in significantly higher yield than others (Table 4). Wheat yield was influenced by growing season rainfall, and it was found to be higher in the first year than in second year. The yield and yield attributes differed significantly due to tillage and weed control measures. Zero-tillage with residue retention had significantly greater number of wheat grains/ear, and 1000-grain weight resulting in higher grain yield.

This might have resulted from greater photosynthesis, and, hence, better translocation of photosynthates, besides larger sink and stronger reproductive phase, as reflected in the greater number of effective tillers/m row, grains/ear and 1000-grain weight. Also there may be a positive impact on soil water balance resulting from maize crop residue on the soil surface under no-till management. Maize residue might have played a role in suppressing soil evaporation, resulting in enhanced soil water retention, increased deep water percolation, and increased wheat yields. Soil organic carbon is increased and soil erosion potential is reduced in reduced tillage and intensified cropping. Ram *et al*. (2012) observed higher bulk density and cumulative infiltration in no tillage compared with con-

Table 5. Cost of cultivation, net returns and net benefit-cost ratio of wheat as affected by different weed control and tillage treatment (mean of 2 years)

Treatment	Tillage treatments during winter season	Cost of cultivation ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Net benefit: cost ratio
Weed control during kharif season				
Weedy check (T_1)	CT	17.65	32.9	1.86
	ZT+R	23.15	28.4	1.22
	ZT	17.95	32.25	1.79
Atrazine 0.75 kg /ha + pendimethalin 0.75 kg/ha (tank-mix PE) (T_2)	CT	18.7	34.75	1.85
	ZT+R	23.15	37.6	1.62
	ZT	17.95	35.3	1.96
Atrazine 1.0 kg/ha + hand weeding at 30 DAS (T_3)	CT	18.7	39.3	2.09
	ZT+R	23.15	39.4	1.7
	ZT	17.95	38.1	2.12
Atrazine 1.0 kg/ha +mustard residue mulch @ 5 t/ha (T_4)	CT	18.7	40.0	2.14
	ZT+R	23.15	40.15	1.73
	ZT	17.95	38.85	2.16
Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE) (T_5)	CT	18.7	47.05	2.51
	ZT+R	23.15	47.25	2.03
	ZT	17.95	45.85	2.55
*KNO_3 (6%) + pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE) (T_6)	CT	18.7	43.65	2.33
	ZT+R	23.15	43.8	1.89
	ZT	17.95	42.5	2.36
Pendimethalin 0.75 kg/ha + chlorimuron 0.006 kg/ha (tank-mix PE) (T_7)	CT	18.7	33.3	1.77
	ZT+R	23.15	30.75	1.32
	ZT	35.9	66.1	1.84
Pendimethalin 0.75 kg/ha PE followed by imazethapyr 0.050 kg/ha POE with sand (T_8)	CT	18.7	39.45	2.10
	ZT+R	23.15	39.6	1.71
	ZT	17.95	38.25	2.13
Pendimethalin 0.75 kg/ha PE fb chlorimuron 0.006 kg/ha POE with sand (T_9)	CT	18.7	38.55	2.06
	ZT+R	23.15	38.7	1.66
	ZT	17.95	37.35	2.07
Brown manuring (*Sesbania* @ 5 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS) (T_{10})	CT	18.7	33.4	1.78
	ZT+R	23.15	36.5	1.57
	ZT	17.95	34.2	1.90
Brown manuring (*Sesbania* @ 10 kg/ha+ 2,4-D 0.75 kg/ha at 25 DAS) (T_{11})	CT	18.7	33.15	1.77
	ZT+R	23.15	36.2	1.56
	ZT	17.95	33.9	1.88
Weed-free check (T_{12})	CT	21.45	45.95	2.14
	ZT+R	25.9	45.75	1.76
	ZT	20.7	45.3	2.19

*KNO_3 was applied separately

ventional tillage. Fischer *et al*. (2002) reported that, in the maize-wheat rotation, ZT with residue retention was clearly superior to the other tillage-residue combinations, and during dry periods, showed less wilting. The use of surface residue coverage is an integral part of any successful conservation tillage system.

Economics

Net returns and net benefit: cost was the highest with application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha), closely followed by weed-free check treatment (Table 5). Gross returns of wheat varied according to treatments adopted during the rainy and winter season in both the years and was found to be higher for weed-free check in both the years. All zero-tilled treatments gave higher gross and net returns than those obtained under conventional-tilled or zero-tilled with residue retention. Pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha (tank-mix PE) with or without KNO_3 (6%) application during rainy season in maize resulted in higher net returns, as well as net benefit: cost in wheat under zero-tilled than in conventional-tilled or zero-tilled with residue.

Weed-free check as usual resulted in the highest yields of wheat. Accordingly, the gross returns were higher in it than in other treatments. But, due to the higher cost incurred in hand weeding, net returns and net benefit: cost were found to be lower. Singh *et al.* (2003) reported similar variation in net returns and benefit: cost among treatments due to variation in yield and expenditure incurred by the treatments. The cost of cultivation, gross and net returns for wheat under conventionally tilled or zero-tilled wheat with and without residue (Table 5) varied among the treatments, mainly due to tillage practices and residues, and hand weeding adopted only in weed-free check. Conventional tilled and zero tilled wheat with residue retention was dearer than zero-tilled without residue due to ploughing and harrowing costs and residue cost incurred. But there was only a marginal variation in cost of cultivation between these treatments.

The positive impacts of residue retention in soil physico-chemical properties offset the cost incurred in residue retention of zero-tillage. Ram *et al*. (2012) reported higher net returns from the maize-wheat system in no tillage than with conventional tillage. We also observed higher net returns and

net benefit: cost in pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha as tank-mix pre-emergence application under zero-tillage in wheat, probably due to residual effect and the interaction between rainy season herbicide application and tillage treatments.

Thus, the results show that previous *kharif* season weed control treatments showed residual effect on weeds. The tank-mix pre-emergence application of pendimethalin 0.75 kg/ha + imazethapyr 0.050 kg/ha could show a higher residual effect and was superior to other treatments. The effect of this treatment was more prominent in ZT with residue compared to other tillage treatments. Therefore, this treatment in combination with zero tillage + residue is worth recommending for weed control in maize *vis- a- vis* for its residual effect in wheat.

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