

Weed competition, yield attributes and yield in soybean (*Glycine max*)–wheat (*Triticum aestivum*) cropping system as affected by herbicides

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ABSTRACT

In a field experiment, 8 weed-control treatments, viz. pendimethalin 1.5 kg/ha (pre), imazethapyr 200 g/ha (pre), quizalofop ethyl 60 g/ha (early post), imazethapyr 75 g/ha (pre) followed by (fb.) imazethapyr 75 g/ha (early post), quizalofop ethyl 50 g/ha + chlorimuron ethyl 4 g/ha (early post), pendimethalin 1.5 kg/ha (pre) fb. chlorimuron ethyl 4 g/ha (early post), hand-weeding (twice) and weedy check) in soybean [*Glycine max* (L.) Merr.] and 3, viz. weedy check, isoproturon 1.0 kg/ha + 2,4-D 0.50 kg/ha and isoproturon 0.75 kg/ha + 2,4-D 0.50 kg/ha, in wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] were evaluated in soybean–wheat cropping system during 2009–10 and 2010–11 at Palampur, Himachal Pradesh. Soybean crop was found infested with *Commelina benghalensis* L., *Echinochloa colona* (L.) Link., *Aeschynomene indica* L., *Ageratum conyzoides* L., *Panicum dichotomiflorum* L., *Digitaria sanguinalis* (L.) Scop., *Eleusine indica* (L.) Gaertn and *Cyperus* sp. Pendimethalin 1.5 kg/ha (pre) fb. chlorimuron ethyl 4 g/ha (early post) effectively managed *Commelina*, *Echinochloa*, *Digitaria*, *Ageratum* and *Cyperus* sp. and resulted in significantly higher yield attributes (branches/plant, pods/plant and 1,000-seed weight) and seed yield (1.87 and 1.83 t/ha). Uncontrolled weed growth throughout the cropping season in soybean reduced its yield by 59.9% during 2009 and 41.0% during 2010 compared to pendimethalin fb chlorimuron ethyl. Herbicide combinations were better than herbicides alone in influencing soybean-equivalent yield and net returns. In wheat, *Phalaris minor* L. and *Avena ludoviciana* L. were important weeds during both the years. Isoproturon 1.0 kg/ha + 2,4-D 0.50 kg/ha and isoproturon 0.75 kg/ha + 2,4-D 0.50 kg/ha were comparable in controlling *Phalaris*, *Avena* and other weeds (*Lolium*, *Vicia* and *Coronopus*) in wheat. Compared to isoproturon 1.0 kg/ha + 2,4-D 0.50 kg/ha, weedy check in wheat reduced its yield by 17.3 and 17.1% during 2009–10 and 2010–11 respectively. Residual effects of treatments applied in soybean were not observed on weeds and yield of wheat crop. Similarly, residual effects of treatments applied in wheat were not significant on soybean weeds and yield.

Key words : 2,4-D, Chlorimuron, Crop protection, Herbicide, Imazethapyr, Isoproturon, Pendimethalin, Quizalofop, Soybean

Among various cropping systems prevalent in north India, maize–wheat is most popular particularly in hilly rainfed areas. Both, maize and wheat are heavy feeders, and exhaust the soil nutrients to the maximum. Soybean has replaced largely maize particularly in pockets wherein there is a problem of monkeys, wild boars and porcupines. Thus, soybean–wheat is a potential cropping system in the northern hills of India. In India, soybean is cultivated in an area of 9.3 million ha with an annual production of 10.47 million tonnes and average productivity of 1,120 kg/ha (AICRPS, 2010). In Himachal Pradesh, it is cultivated on 0.6 thousand hectares with a production of 0.8 thousand

tonnes and average productivity of 1,333 kg/ha (FAI, 2007). Among the various factors of low productivity of soybean, competition by weeds is the major one. In order to achieve enhanced crop production and higher benefits from applied inputs, weeds must be kept under check using any of the safe and effective weed-control measures. Presently recommended pre-emergence herbicides are either having narrow spectrum of weed control or less effective against different flushes of broad-leaf weeds. Moreover, in case the pre-emergence application of herbicides is missed due to one or other reason, alternative post-emergent herbicides for controlling weeds in soybean are required. However, in wheat mixed weed flora is effectively taken care of by using isoproturon and 2,4-D. Hence, there was an urgent need to find out effective post-emergence herbicides alone or in combination having broad spectrum

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activity and longer persistence for control of weeds in soybean–wheat cropping system.

MATERIALS AND METHODS

A field experiment was conducted during 2009–10 and 2010–11 at Palampur (32°62' N, 76°32' E, 1,280 m altitude). The soil was silty clay loam, acidic (5.6), low in available nitrogen (204.6 kg/ha), medium in available phosphorus (18.1 kg/ha) and high in available potassium (308.2 kg/ha). In the rainy (*kharif*) season of 2009–10, eight weed-control treatments, viz. pendimethalin 1.5 kg/ha (pre), imazethapyr 200 g/ha (pre), quizalofop ethyl 60 g/ha (early post), imazethapyr 75 g/ha (pre) fb. imazethapyr 75 g/ha (early post), quizalofop ethyl 50 g/ha + chlorimuron ethyl 4 g/ha (early post), pendimethalin 1.5 kg/ha (pre) fb. chlorimuron ethyl 4 g/ha (early post), hand-weeding (twice) and weedy check in soybean were tested in randomized block design with 3 replications. Subsequently during, the winter (*rabi*) season of 2009–10 each plot was divided into 3 equal parts and 3 weed-control treatments, viz. weedy check, isoproturon 1.0 kg/ha + 2,4-D 0.50 kg/ha and isoproturon 0.75 kg/ha + 2,4-D 0.50 kg/ha (post-emergence), in wheat were assigned to these plots. Thus with 8 weed-control treatments in soybean as main plot factors and 3 treatments in wheat as subplot factors were analyzed in split-plot design with three replications. 'Harit Soya' variety of soybean was sown in rows 45 cm apart on 18 June, 2009 and 5 June, 2010 using 75 kg seed/ha. The crop was fertilized with 20 kg N, 60 kg P₂O₅ and 40 kg K₂O/ha as basal dose. Wheat variety 'HPW 155' was sown on 11 November, 2009 and 3 November, 2010 using 100 kg seed/ha. The crop was fertilized with 120 kg N, 60 kg P₂O₅ and 30 kg K₂O/ha. In each crop, required amount of N, P and K was supplied through urea, single superphosphate and muriate of potash respectively. Rest of the management practices were in accordance with the recommended package of practices for individual crop. Weed count was recorded by placing 50 cm × 50 cm quadrates at 2 random places in each plot and after drying them in hot air oven (72°C for 72 hr), weed dry weight was recorded. Herbicides were applied with the help of Maruyama Power Sprayer using flat-fan nozzle. Yield was recorded from net plot. Economics of treatment was computed based on prevalent prices of inputs used and output realized.

RESULTS AND DISCUSSION

Effect on weeds

Soybean: The population of weeds was the maximum at 60 days after sowing (DAS) and decreased thereafter, probably owing to the suppressive effect of vigorous crop growth. *Commelina benghalensis* was the most predomi-

nant weed in soybean (Singh *et al.*, 1992; Rajput and Kushwah, 2004) constituting 43.36 and 57.87% of total weed flora during 2009 and 2010 respectively. The other weeds were *Echinochloa colona* (18.04 and 15.02% during 2009 and 2010, respectively), *Aeschynomene indica* (3.78 and 2.73%), *Ageratum conyzoides* (3.68 and 4.91%), *Panicum dichotomiflorum* (11.53 and 5.12%), *Digitaria sanguinalis* (4.25 and 3.69%), *Eleusine indica* (3.54 and 3.48%) and *Cyperus* sp. (9.21 and 5.12%). All treatments except pre-emergence application of pendimethalin alone were significantly superior to untreated check in reducing the population of *C. benghalensis*. But pendimethalin fb. chlorimuron-ethyl (EP) significantly reduced its count (Table 1). Ram and Singh (2011) reported similar results. *Aeschynomene indica* population was significantly lower under imazethapyr 200 g/ha, pendimethalin fb. chlorimuron ethyl, hand-weeding twice and pendimethalin. Application of pendimethalin fb. chlorimuron ethyl, quizalofop ethyl + chlorimuron ethyl, imazethapyr fb. imazethapyr, quizalofop ethyl and imazethapyr maintained their superiority in controlling *Ageratum* until harvest. Hand-weeding (twice) was found to be ineffective against *Ageratum* owing to its frequent emergence especially where other weeds eliminated. Compared to weedy check, all weed-control treatments had significantly lower density of *Cyperus* sp. All the weed-control treatments except hand-weeding and imazethapyr alone were found to be significantly superior to weedy check in reducing population count of *Echinochloa colona*. The better effectiveness of pendimethalin (Shim *et al.*, 2000) and quizalofop (Anyszka and Dobrzanski, 1999) against *Echinochloa* sp. has been documented. Followed by application of imazethapyr had taken care the subsequent flushes of this weed effectively. Better efficacy of quizalofop ethyl, quizalofop ethyl + chlorimuron ethyl and pendimethalin fb. chlorimuron ethyl against *Panicum dichotomiflorum* was observed during both the years. However, during 2009, pendimethalin alone was also effective in reducing its count compared to untreated check. Shim *et al.* (2000) also reported effective control of *Panicum* with pendimethalin. During 2010, all weed-control treatments had significantly reduced the density of *Digitaria sanguinalis* compared to unweeded check. Quizalofop ethyl, quizalofop ethyl + chlorimuron ethyl and pendimethalin fb. chlorimuron ethyl being statistically similar were found superior to hand-weeding (twice) and imazethapyr in decreasing population of *Eleusine*. Pendimethalin fb. chlorimuron ethyl remaining at par with quizalofop ethyl + chlorimuron ethyl during both the years and quizalofop ethyl, imazethapyr and hand-weeding during 2009, resulted in significantly lower total weed count as compared to other treatments. Mishra and Singh (2005)

Table 1. Effect of herbicidal treatments on count (No./m²) of weeds at maximum population stage (60 days after sowing) in soybean

Treatment	Rate (g/ha)	Time	<i>Commelina benghalensis</i>		<i>Aeschynomene indica</i>		<i>Ageratum conyzoides</i>		<i>Cyperus</i> sp.		<i>E. colona</i>		<i>P. dichotomiflorum</i>		<i>D. sanguinalis</i>		<i>E. indica</i>		Total weed count		
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	
<i>Soybean</i>																					
Pendimethalin	1,500	Pre	9.1 (86)	11.0 (122)	1.9 (4)	1.8 (4)	6.4 (66)	7.1 (57)	2.5 (9)	2.1 (6)	4.0 (17)	4.1 (17)	1.6 (2)	2.2 (6)	1.0 (0)	1.9 (4)	1.9 (4)	2.0 (4)	11.0 (124)	12.9 (167)	
Imazethapyr	200	Pre	4.5 (20)	9.3 (88)	1.3 (1)	2.0 (4)	5.3 (46)	4.5 (28)	3.3 (13)	3.0 (10)	6.3 (46)	5.2 (31)	3.6 (17)	2.6 (9)	3.3 (12)	2.6 (10)	1.8 (4)	1.8 (4)	11.0 (121)	12.6 (160)	
Quizalofop ethyl	60	EP	6.8 (52)	9.2 (84)	2.6 (7)	3 (3)	4.6 (30)	3.7 (17)	2.5 (7)	2.8 (9)	1.3 (1)	2.3 (6)	1.3 (1)	1.8 (4)	2.3 (10)	3.4 (15)	1.6 (5)	1.5 (4)	8.5 (81)	10.9 (12)	
Imazethapyr fb.	75 fb.	Pre fb.	4.4 (20)	6.6 (43)	2.7 (8)	1.6 (3)	3.6 (19)	4.0 (22)	1.4 (2)	1.1 (0)	1.0 (0)	2.8 (8)	4.8 (26)	3.0 (12)	3.6 (18)	2.5 (8)	2.6 (9)	2.3 (6)	8.7 (80)	9.0 (82)	
imazethapyr	75	EP	8.0 (60)	6.4 (41)	2.2 (5)	1.9 (4)	1.6 (4)	2.5 (7)	1.1 (0)	1.7 (3)	1.8 (4)	1.9 (4)	1.0 (0)	1.6 (2)	1.8 (7)	1.8 (4)	1.1 (0)	1.6 (3)	8.8 (82)	7.8 (61)	
Quizalofop ethyl + chlorimuron ethyl	50 + 4	EP	5.2 (29)	8.0 (60)	1.3 (1)	1.6 (2)	1.8 (5)	2.1 (6)	1.4 (1)	1.0 (0)	3.4 (12)	2.7 (8)	2.6 (13)	1.6 (3)	2.5 (9)	1.3 (1)	1.3 (1)	1.3 (1)	7.6 (61)	7.0 (51)	
Pendimethalin fb.	1,500	Pre fb.	4.2 (18)	7.2 (52)	1.5 (2)	1.6 (3)	6.3 (54)	6.3 (43)	3.2 (12)	2.6 (7)	5.3 (32)	6.2 (40)	3.3 (12)	3.3 (7)	1.8 (7)	2.3 (6)	1.6 (2)	2.2 (6)	9.1 (84)	11.6 (136)	
chlorimuron ethyl	fb. 4	EP	10.6 (113)	12.2 (149)	3.0 (9)	2.3 (6)	7.1 (63)	7.6 (60)	6.0 (42)	4.1 (19)	7.4 (58)	6.6 (45)	5.7 (37)	3.2 (13)	4.7 (52)	5.7 (37)	2.7 (8)	2.6 (8)	17.4 (308)	16.7 (281)	
Hand weeding	Twice	25 and 40 DAS	0.69	0.40	0.26	0.37	1.80	0.97	0.60	0.37	0.74	0.67	0.62	0.36	1.16	0.66	0.41	0.15	0.95	0.52	
Weedy check			2.1	1.2	0.8	NS	NS	2.9	1.8	1.1	2.2	2.0	1.9	1.1	NS	1.9	NS	NS	2.8	1.6	
SEM±																					
CD (P=0.05)																					
<i>Wheat</i>																					
Weedy check			-	8.4 (75)	-	2.0 (4)	-	2.0 (7)	-	2.7 (9)	-	4.0 (21)	-	2.7 (9)	-	1.9 (5)	-	2.3 (6)	-	11.3 (138)	
Isoproturon + 2,4-D	1,000 + 500	Post	-	8.5 (75)	-	1.6 (3)	-	2.2 (7)	-	2.4 (8)	-	4.5 (25)	-	2.3 (7)	-	2.0 (5)	-	1.9 (5)	-	11.4 (136)	
Isoproturon + 2,4-D	750 + 500	Post	-	8.5 (80)	-	2.0 (4)	-	2.1 (7)	-	1.9 (4)	-	3.4 (13)	-	1.9 (5)	-	2.0 (5)	-	1.6 (3)	-	10.6 (124)	
SEM±																					
CD (P=0.05)			-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	

Values given in parentheses are the means of original values; EP, early post E., *Echinochloa*; P., *Panicum*; D., *Digitaria*, *E. Eleusine*

Table 2. Effect of herbicidal treatments on count (No./m²) of weeds (60 DAS) in wheat

Treatment	Rate (g/ha)	Time	<i>P. minor</i>		<i>A. ludoviciana</i>		<i>L. temulentum</i>		<i>V. sativa</i>		<i>C. didymus</i>		Total weed count	
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
<i>Soybean</i>														
Pendimethalin	1,500	Pre	8.3 (77)	7.9 (67)	5.0 (27)	5.5 (32)	1.9 (4)	1.3 (2)	2.1 (5)	1.1 (0)	1.3 (1)	1.0 (0)	10.3 (115)	9.8 (101)
Imazethapyr	200	Pre	8.6 (84)	8.7 (85)	7.2 (53)	5.9 (36)	1.3 (1)	1.6 (3)	1.2 (1)	2.2 (5)	1.0 (0)	1.0 (0)	11.5 (139)	11.1 (129)
Quizalofop ethyl	60	EP	12.0 (152)	10.9 (125)	5.2 (28)	5.4 (28)	1.0 (0)	2.5 (6)	1.8 (4)	1.6 (3)	1.0 (0)	1.6 (3)	13.2 (184)	12.7 (165)
Imazethapyr fb.	75 fb.	Pre fb.	11.1 (132)	10.6 (117)	6.8 (53)	5.9 (38)	1.3 (1)	1.4 (1)	2.0 (4)	2.7 (8)	1.0 (0)	1.1 (0)	13.3 (190)	12.8 (166)
Imazethapyr Quizalofop ethyl + chlorimuron ethyl	75 50 + 4	EP EP	9.6 (98)	8.9 (85)	5.0 (25)	5.9 (35)	1.9 (4)	1.9 (4)	2.8 (9)	2.3 (7)	1.0 (0)	1.2 (1)	11.4 (136)	11.4 (132)
Pendimethalin fb.	1,500	Pre	8.1 (78)	7.5 (68)	6.5 (49)	5.4 (36)	1.6 (3)	1.2 (1)	2.3 (6)	2.0 (4)	1.0 (0)	1.2 (1)	10.9 (136)	10.3 (109)
chlorimuron ethyl	fb. 4	fb. EP	8.0 (66)	8.7 (78)	7.8 (72)	5.9 (35)	1.1 (0)	2.5 (7)	1.2 (1)	2.7 (8)	1.1 (0)	1.4 (1)	11.6 (140)	11.3 (130)
Hand-weeding	Twice	25 and 40 DAS	7.8 (68)	7.7 (62)	7.9 (67)	6.3 (45)	1.4 (2)	1.6 (3)	1.7 (3)	1.5 (2)	1.0 (0)	1.0 (0)	11.7 (140)	10.4 (112)
Weedy check			1.57 NS	1.33 NS	1.20 NS	0.80 NS	0.41 NS	0.44 NS	0.43 NS	0.48 NS	0.11 NS	0.16 NS	1.55 NS	0.79 NS
SEM±														
CD (P=0.05)														
<i>Wheat</i>														
Weedy check			11.1 (135)	9.9 (108)	7.2 (56)	6.4 (45)	1.6 (3)	2.0 (4)	2.91 (10)	1.63 (3)	1.2 (1)	1.3 (1)	14.0 (203)	12.5 (161)
Isoproturon + 2,4-D	1,000 + 500	Post	7.8 (67)	8.1 (71)	5.8 (39)	5.2 (28)	1.2 (1)	1.7 (3)	1.13 (1)	2.20 (6)	1.0 (0)	1.2 (1)	10.0 (108)	10.3 (110)
Isoproturon + 2,4-D	750 + 500	Post	8.7 (81)	8.5 (79)	6.3 (46)	5.6 (34)	1.5 (2)	1.6 (3)	1.62 (3)	2.21 (6)	1.0 (0)	1.1 (0)	11.2 (131)	10.9 (122)
SEM±			0.35	0.42	0.36	0.34	0.13	0.19	0.17	0.26	0.07	0.14	0.39	0.38
CD (P=0.05)			1.0	1.2	1.0	1.0	NS	NS	0.5	NS	NS	NS	1.1	1.1

Values given in parenthesis are the means of original values; EP, early post
C., *Commelina*; A., *Ageratum*; E., *Echinochloa*; P., *Panicum*; D., *Digitaria*
P., *Phalaris*; A., *Avena*; L., *Lolium*; V. *Vicia*; C., *Comopus*

also reported significant reduction in the total weed count due to application of herbicides as compared to weedy check.

Weed-control treatments in wheat did not significantly influence the count of any weed in soybean indicated that there were no residual effect of treatments applied in wheat on soybean.

Wheat: The wheat crop was mainly infested with grassy weeds, viz. *Phalaris minor* (65.9 and 67.1% during 2009–10 and 2010–11 respectively), *Avena ludoviciana* (27.3 and 28.0%) and *Lolium temulentum* (1.5 and 2.5%). Broad-leaf weeds (*Vicia* and *Coronopus*) constituted 5.4 and 2.5% of the total weed flora in 2009–10 and 2010–11 respectively. In general, the count of all the weeds was maximum at 60 DAS and gradually decreased thereafter. Density of *A. ludoviciana* was more during 2009 than 2010. Residual effects of treatments applied in soybean were not significant on weeds in wheat (Table 2). Application of isoproturon 1,000 g/ha + 2,4-D 500 g/ha behaving statistically alike with isoproturon 750 g/ha + 2,4-D 500 g/ha resulted in significantly lower count of *Phalaris minor*, *Avena ludoviciana*, *Vicia sativa* and total weed population in wheat as compared to weedy check. Similar results were reported by Pandey *et al.* (2007a) and Bharat and Kachroo (2007).

Effect on crop

Soybean: Weed-control treatments applied in the soybean did not influence days taken to maturity. There appeared the dominance of genetic factors over the environmental ones. Pendimethalin fb. chlorimuron ethyl being statistically similar to imazethapyr fb. imazethapyr, quizalofop ethyl + chlorimuron ethyl and hand-weeding (twice) during both the years resulted in significantly higher soybean seed yield (Table 3). Superior performance of these treatments was owed to increase in yield attributes owing to effective weed control. Balyan and Malik (2003) reported similar results. Improvement in yield attributes and yield owing to effective weed management was also reported by Singh *et al.* (2006) and Patil *et al.* (2002). Weeds in weedy check reduced the seed yield of soybean by 59.9 and 41.0% during 2009 and 2010 respectively, as compared to pendimethalin fb. chlorimuron ethyl. Mishra and Singh (2009) reported 86% reduction in seed yield of soybean due to weeds. Trends in straw yield of soybean were almost similar as that of seed yield. The best treatment, i.e. pendimethalin fb. chlorimuron ethyl resulted in 176.0 and 163.6% higher straw yield than unweeded check during 2009 and 2010 respectively. There were no

Table 3. Effect of herbicidal treatments on yield attributes and yield in soybean

Treatment	Rate (g/ha)	Time	Branches/plant (No.)		Pods/plant (No.)		1,000-seed weight (g)		Seed yield (t/ha)		Straw yield (t/ha)	
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
<i>Soybean</i>												
Pendimethalin	1,500	Pre	8.2	8.5	114.2	108.3	163.1	160.3	1.33	1.42	4.75	5.25
Imazethapyr	200	Pre	8.1	8.6	106.4	114.4	167.6	165.3	1.34	1.45	4.62	5.77
Quizalofop ethyl	60	EP	8.4	8.7	111.1	118.2	174.8	165.0	1.38	1.49	4.43	5.19
Imazethapyr fb. imazethapyr	75 fb. 75	Pre fb. EP	9.1	9.0	128.4	127.1	177.0	174.8	1.79	1.77	5.29	5.44
Quizalofop ethyl + chlorimuron ethyl	50 + 4	EP	9.1	9.1	127.9	127.5	177.6	179.2	1.67	1.66	5.17	5.85
Pendimethalin fb. chlorimuron ethyl	1,500 fb. 4	Pre fb. EP	9.2	9.4	140.2	146.7	183.7	187.7	1.87	1.83	7.26	6.59
Hand-weeding	Twice	25 and 40 DAS	8.8	8.7	119.7	114.1	162.6	165.3	1.63	1.65	5.63	5.02
Weedy check			7.5	7.4	84.1	84.7	147.8	150.4	0.75	1.08	2.63	2.50
SEM±			0.21	0.24	8.90	6.57	5.70	3.92	0.14	0.05	0.69	0.31
CD (P=0.05)			0.6	0.7	27.0	19.9	17.3	11.9	0.43	0.17	2.09	0.93
<i>Wheat</i>												
Weedy check	-		-	8.9	-	121.6	-	166.5	-	1.52	-	5.26
Isoproturon + 2,4-D	1,000 + 500	Post	-	8.7	-	114.1	-	171.0	-	1.57	-	5.10
Isoproturon + 2,4-D	750 + 500	Post	-	8.5	-	117.2	-	168.0	-	1.54	-	5.24
SEM±			-	0.15	-	3.86	-	2.26	-	0.03	-	0.11
CD (P=0.05)			-	NS	-	NS	-	NS	-	NS	-	NS

EP, early post

residual effect of treatments applied in wheat on seed and straw yield of soybean as the treatments were not significantly different.

Wheat: Treatments applied in soybean did not significantly influence yield attributes and yield of wheat. As in soybean, weed-control treatments applied in the wheat did not influence days taken to maturity in wheat. All the yield-contributing characters of wheat were significantly affected by different weed-control treatments applied in wheat. Isoproturon 1,000 g/ha + 2,4-D 500 g/ha behaving statistically alike with isoproturon 750 g/ha + 2,4-D 500 g/ha resulted in significantly higher number of effective tillers, spikelets/spike and 1,000-grain weight as compared to unweeded check during 2009–10 (Table 4). However, isoproturon 1,000 g/ha + 2,4-D 500 g/ha was superior to the latter in influencing effective tillers, spikelets/spike and grain/spike during 2010–11. Similar results were reported by Pandey and Verma (2002) and Nadeem *et al.* (2007). Both treatments applied in wheat were significantly superior to unweeded check in increasing wheat grain and straw yield. Isoproturon 1,000 g/ha + 2,4-D 500 g/ha behaving statistically alike with isoproturon 750 g/ha + 2,4-D 500 g/ha resulted in significantly higher yield during 2009–10. However, during 2010–11, isoproturon 1,000 g/ha + 2,4-D 500 g/ha resulted in the highest grain yield of wheat. These results confirm the findings of Tomar *et al.* (2004) and Pandey *et al.* (2007). Weeds in weedy check reduced the grain yield of wheat by 17.28 and 17.09% compared to the best treatment, i.e. isoproturon 1,000 g/ha + 2,4-D 500 g/ha during 2009–10 and 2010–11 respectively. Both isoproturon 1,000 g/ha + 2,4-D 500 g/ha and isoproturon 750 g/ha + 2,4-D 500 g/ha (7.33 and 8.78 t/ha during 2009–10 and 2010–11 respectively) were comparable in increasing wheat straw yield over weedy check. Since the herbicides applied in soybean and wheat showed shorter persistence, therefore, residual effects of treatments were not significant on weeds or subsequent crop.

Herbicide combinations and hand-weed-

Table 4. Effect of herbicidal treatments on yield attributes and yield of wheat and soybean-equivalent yield

Treatment	Rate (g/ha)	Time	Tillers/ m ² (No.)		Grains /spike (No.)		1,000-seed weight (g)		Seed yield (t/ha)		Straw yield (t/ha)		Soybean equivalent yield (t/ha)	
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
<i>Soybean</i>														
Pendimethalin	1,500	Pre	238.4	211.6	49.1	50.2	44.7	42.1	36.6	32.7	7.59	8.44	2.80	2.72
Imazethapyr	200	Pre	235.9	245.6	50.2	49.7	44.1	40.2	33.6	33.5	7.24	7.81	2.69	2.79
Quizalofop ethyl	60	EP	223.4	249.1	48.9	51.0	45.1	40.4	32.8	31.8	7.28	8.07	2.69	2.76
Imazethapyr fb. imazethapyr	75 fb. 75	Pre fb. EP	248.8	231.8	52.0	50.5	44.2	40.3	38.8	34.4	8.27	9.24	3.34	3.15
Quizalofop ethyl + chlorimuron ethyl	50 + 4	EP	249.7	234.2	49.4	50.4	44.7	40.4	35.8	30.6	7.67	8.74	3.10	2.89
Pendimethalin fb. chlorimuron ethyl	1,500 fb. 4	Pre fb. EP	256.3	257.1	53.0	51.6	45.6	45.7	35.6	33.2	7.49	9.06	3.30	3.16
Hand-weeding	Twice	25 and 40 DAS	245.2	210.9	47.6	50.7	44.7	40.6	36.8	32.3	8.11	7.49	3.11	2.94
Weedy check			200.8	219.3	46.7	49.4	43.7	39.0	33.5	2.92	7.05	7.27	2.09	2.25
SEm±			18.45	16.97	1.44	0.60	0.66	1.28	4.01	2.52	6.38	8.02	0.20	0.12
CD (P=0.05)			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.59	0.35
<i>Wheat</i>														
Weedy check	-		217.0	217.7	46.8	49.1	43.6	39.6	31.6	2.91	6.94	7.49	2.72	2.69
Isoproturon + 2,4-D	1,000 + 500	Post	257.0	252.6	52.6	51.3	45.2	42.2	38.2	3.51	8.08	8.79	2.96	2.97
Isoproturon + 2,4-D	750 + 500	Post	238.0	227.1	49.5	50.9	45.0	41.5	36.5	3.24	7.73	8.51	2.99	2.84
SEm±			10.61	3.89	1.16	0.33	0.48	0.52	1.07	0.90	2.65	3.17	0.06	0.04
CD (P=0.05)			30.6	11.2	3.3	0.9	1.4	1.5	3.1	0.3	0.8	0.9	0.17	0.11

EP, early post

Table 5. Effect of herbicidal treatments on economics in soybean–wheat cropping system

Treatment in soybean	Treatment in wheat		
	Weedy check	Isoproturon 1,000 + 2,4-D 500 g/ha (post)	Isoproturon 750 + 2,4-D 500 g/ha (post)
	Gross returns ($\times 10^3$ ₹/ha/annum)		
Pendimethalin 1,500 g/ha (Pre)	101.1	118.5	112.6
Imazethapyr 200 g/ha (Pre)	99.3	100.2	119.6
Quizalofop ethyl 60 g/ha (EP)	98.2	117.1	103.0
Imazethapyr 75 (Pre) fb. imazethapyr 75 g/ha (EP)	119.0	131.9	134.0
Quizalofop ethyl 50 + chlorimuron ethyl 4 g/ha (EP)	118.4	119.0	122.1
Pendimethalin 1,500 (Pre) fb. chlorimuron ethyl 4 g/ha (EP)	118.7	138.4	134.0
Hand-weeding 25 and 40 DAS	114.1	130.5	124.3
Weedy check	83.1	86.3	85.3
	Net returns ($\times 10^3$ ₹/ha/annum)		
Pendimethalin 1,500 g/ha (Pre)	58.6	72.1	69.8
Imazethapyr 200 g/ha (Pre)	58.2	65.8	72.6
Quizalofop ethyl 60 g/ha (EP)	59.9	71.5	63.3
Imazethapyr 75 (Pre) fb. imazethapyr 75 g/ha (EP)	72.8	89.0	87.5
Quizalofop ethyl 50 + chlorimuron ethyl 4 g/ha (EP)	71.1	78.1	77.3
Pendimethalin 1500 (Pre) fb. chlorimuron ethyl 4 g/ha (EP)	76.5	91.8	87.1
Hand-weeding 25 & 40 DAS	62.2	74.6	70.9
Weedy check	42.6	41.4	44.9
	Benefit: cost ratio		
Pendimethalin 1,500 g/ha (Pre)	1.30	1.59	1.54
Imazethapyr 200 g/ha (Pre)	1.31	1.46	1.62
Quizalofop ethyl 60 g/ha (EP)	1.35	1.60	1.42
Imazethapyr 75 (Pre) fb. imazethapyr 75 g/ha (EP)	1.64	1.98	1.95
Quizalofop ethyl 50 + chlorimuron ethyl 4 g/ha (EP)	1.60	1.74	1.73
Pendimethalin 1,500 (Pre) fb. chlorimuron ethyl 4 g/ha (EP)	1.70	2.02	1.92
Hand-weeding 25 and 40 DAS	1.27	1.51	1.44
Weedy check	0.96	0.93	1.01

ing twice were better than herbicides alone in influencing soybean-equivalent yield (Table 4). During 2009, pendimethalin alone was also at par with herbicide combinations. Imazethapyr fb. imazethapyr resulted in higher soybean equivalent yield (3.34 t/ha) during 2009, whereas during 2010 pendimethalin fb. chlorimuron (3.16 t/ha) was better. Weeds reduced soybean-equivalent yield by 37.4 and 28.8% during 2009 and 2010 respectively. Among the treatments in wheat, isoproturon 750 g/ha + 2,4-D 500 kg/ha and isoproturon 1,000 g/ha + 2,4-D 500 g/ha resulted in similar soybean-equivalent yield during 2009. During 2010, isoproturon 1,000 g/ha + 2,4-D 500 g/ha gave highest soybean equivalent yield (2.97 t/ha).

Economics

Owing to higher seed/grain and straw yields by means of effective weed control, pendimethalin fb. chlorimuron in soybean and isoproturon 1.0 kg/ha + 2,4-D 0.5 kg/ha in wheat resulted in highest system's net returns and benefit: cost ratio. Imazethapyr fb. imazethapyr in soybean and isoproturon 1.0 kg/ha + 2,4-D 0.5 kg/ha in wheat, imazethapyr fb. imazethapyr in soybean and isoproturon

0.75 kg/ha + 2,4-D 0.5 kg/ha in wheat and pendimethalin fb. chlorimuron in soybean and isoproturon 0.75 kg/ha + 2,4-D 0.5 kg/ha in wheat were the next superior treatments in influencing net returns and benefit: cost ratio.

Thus, it can be concluded that in soybean–wheat cropping system for effective weed control and higher yield and returns, pendimethalin fb. chlorimuron ethyl or imazethapyr fb. imazethapyr in soybean and isoproturon 750–1,000 g/ha + 2,4-D 500 g/ha in wheat were the effective treatments. Treatments in soybean or wheat did not show any residual influence on subsequent crop. Higher grain yield were obtained with application of herbicides in combination as compared to alone application of herbicides. Therefore, weed control is equally important for both the crops in sequence.

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