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Bio-efficacy of alone and mixture of herbicides against complex weed flora in wheat (*Triticum aestivum*) under sub-tropical conditions

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ABSTARCT

A field experiment was conducted during winter season of 2011-12 and 2012-13 at Research Farm, AICRP on wheat and barley, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu to study the effect of different herbicides and its mixtures on broad spectrum weed management and productivity of wheat (*Triticum aestivum* L.). Unchecked weeds growth caused 40.13 to 57.18% reduction in grain yield of wheat. The lowest weed density and dry matter of weeds and higher yield and yield attributes were found with application of ready mix formulations of clodinafop+metribuzin (60+210 g/ha), sulfosulfuron+metsulfuron (32 g/ha) and pinoxaden+metribuzin (40+210 g/ha). The maximum weed control efficiency and lowest weed index were observed with clodinafop+metribuzin (60+210 g/ha) followed by sulfosulfuron+metsulfuron (32 g/ha) and pinoxaden+metribuzin (40+210 g/ha). The alone application of clodinafop 60 g/ha was significantly reduced the weed density and weed dry weight than alone application of metribuzin 210 g/ha, pinoxaden @ 40 g/ha and sulfosulfuron 25 g/ha but these were significantly lower than weedy check.

Key words: Bio-efficacy, Weed control efficiency, Weed density, Weed flora, Weed index

Wheat (*Triticum aestivum* L.) is an important *rabi* cereal crop and occupies a significant position in the economy of India. The total area and production of wheat in India is about 31.34 million ha and 95.91 million tonnes, respectively with average productivity of 3061 kg/ha. In Jammu and Kashmir, wheat is grown on 0.29 million ha with an average productivity of 1595 kg/ha (Anonymous 2014). Although, the soil and climatic conditions of India are favourable for wheat production but its per ha yield is very low in India and as well as Jammu and Kashmir. Among various factors, weeds infestation is one of the main causes of low wheat yield not only in Jammu and Kashmir but all over the India. Heavy infestation of weeds alone causing 33-50% reductions in yield is a serious constraint in sustaining productivity of wheat (Singh *et al.* 1997, Azad 2003). Weeds are the major deterrent factor to the development of a more sustainable agricultural system. With the adoption of high-yielding dwarf varieties of wheat, *Phalaris minor* (little canary grass) has become a serious problem in north-western parts of India in rice-wheat system (Chopra *et al*. 2008). According to previous studies to tackle the resistance problem, clodinafop, fenoxaprop and sulfosulfuron have been recommended for control of grassy weeds in wheat (Walia *et al*. 1998, Chhokar and Malik 2002). Continuous use of same herbicide for many years resulted in development of resistance against some weeds which happened in case of isoproturon. Therefore, alternate herbicides were needed to tackle the resistance problem (Shoeran *et al*. 2013). Isoproturon, being a cheap weedicide, is still being used in areas of no resistant biotypes, and non-availability of alternative herbicides. The herbicide pinoxaden 5 EC at 40 - 60 g/ha was found very effective and recommended for the control of grassy weeds in wheat without any residual toxicity to succeeding rice and sorghum crops (Walia *et al*. 2007, Punia *et al.* 2008, Yadav *et al*. 2009, Punia and Yadav 2010). Several broad-leaved weeds are becoming a serious problem along with grassy weeds in wheat. For control of broad-leaf weeds, metsulfuron and 2,4-D are being widely used, but these herbicides do not provide any control of *Convolvulus arvensis, Solanum nigrum* and *Malva parviflora* (Punia *et al*. 2006, Walia and Singh 2006). There is need for tank mix or sequential application of herbicides like 2,4-D and metsulfuron for the control of complex weed flora. Tank mix application of 2,4-D with clodinafop and fenoxaprop gave reduced control of grassy weeds because of antagonism between 2,4-D and these grass weed killers (Banga and Yadav 2004, Punia *et al*. 2004, Yadav *et al*. 2010). So there was urgent need for broad spectrum herbicides which can provide effective control of both grassy as well as broad-leaf and other weeds in wheat crop. Keeping this in view, efforts

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were made to explore the possibility of using alone and tank mixture of different herbicides have been evaluated.

MATERIALS AND METHODS

A field experiment was conducted during winter season of 2011-12 and 2012-13 at Research Farm of All India Coordinated Wheat and Barley Improvement Project, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu (32° 40' N latitude and 74° 58' E longitude at an altitude of 332 m above mean sea level) to examine the bio-efficacy of herbicides against grassy and broad-leaved weed flora in wheat. The soil of the experimental field was sandy loam in texture having a pH of 8.1, low in organic carbon and nitrogen, medium in available phosphorus and potassium. The experiment was laid out in randomized block design with 14 treatments and three replications. The treatments consisted of metribuzin 210 g/ha, clodinafop 60 g/ha, pinoxaden 40 g/ha, sulfosulfuron 25 g/ha and premix formulations of clodinafop + metribuzin 60+210 g/ha, pinoxaden + Metribuzin 40 + 210 g/ha, sulfosulfuron + metribuzin 25 + 210 g/ha, fenoxaprop + metribuzin 120 + 210 g/ha, sulfosulfuron + metsulfuron 32 g/ha, mesosulfuron + iodosulfuron 14.4 g/ha, clodinafop + metsulfuron 60 + 4 g/ha, isoproturon + 2,4-D 1000 + 500 g/ha along with weed free and weedy check . All the herbicides were applied at 30 days after sowing by using a Knapsack sprayer fitted with flood jet nozzle with spray volume of 500 liters water/ha. The wheat variety RSP 561 was sown on 14th and 17th November during *rabi* seasons with a recommended seed rate of 100 kg/ha. Recommended doses of 100 kg N + 50 kg P_2O_5 + 25 kg K_2O/ha were uniformly applied. Full dose of P and K, and half N were applied as basal at the time of sowing, whereas rest of the N was given in two equal splits as top dressing at first irrigation and at booting stage. Crop was raised under irrigated condition. Nitrogen was estimated by Kjeldhal's method (Jackson 1973) from ground samples of grain and straw and weed samples. Phosphorus and potassium of samples were estimated following standard methods described by Jackson (1973). The weed count and weed dry matter accumulation were recorded at 60 and 120 days after sowing using quadrate of 1 m^2 size. Weed control efficiency (WCE) and weed index has been calculated with the formula: WCE= (x-y) 100/x, where; x = weed dry weight in weedy check and y = weed dry weight in treated plot and WI= (x-y) 100/x, where; x = yield from untreated plot and y = yield from treated plots.

Table 1 Relative density of individual weed species to the total weed density in wheat crop under weedy condition

Weed species	Relative density (%) at 60 days after sowing	
	2011-12	2012-13
Grassy weeds		
Phalaris minor	38.63	34.47
Avena ludoviciana	4.45	3.35
Broad leaved weeds		
Anagallis arvensis	22.40	18.02
Rumex maritimus	9.12	7.87
Medicago denticulata	7.46	6.65
Chenopodium album	5.53	7.21
Vicia sativa	3.95	4.76
Melilotus indica	4.16	10.93
Trachyspermum spp.	2.62	4.26
Others	1.68	2.48

Table 2 Effect of herbicides on yield and yield attributes of wheat crop

Treatment	Dose (g/ha)	Ear heads/ m^2		Grains/ earhead		1000 seed weight (g)		Grain yield (q/ha)		Straw yield (q/ha)	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Metribuzin	210	374.7	320	32.2	27.15	36.5	35.30	38.70	30.67	54.35	44.74
Clodinafop	60	388.8	356	35.9	30.81	38.0	36.87	43.90	40.44	62.61	56.46
Pinoxaden	40	375.9	324	32.8	27.67	36.8	35.77	38.12	32.04	54.04	46.00
Sulfosulfuron	25	370.6	317	31.7	26.56	36.2	35.20	35.75	29.66	52.40	42.18
Clodinafop + Metribuzin	60 + 210	396.1	388	37.3	31.42	39.6	39.70	47.48	48.47	68.14	68.80
Pinoxaden + Metribuzin	40 + 210	395.8	391	36.9	30.79	39.1	38.23	46.78	46.05	66.88	64.35
Sulfosulfuron + Metribuzin	25 + 210	385.7	336	34.4	29.04	37.2	37.60	41.39	36.65	59.90	51.91
Fenoxaprop + Metribuzin	120 + 210	382.8	327	34.1	28.17	36.9	36.93	40.46	34.06	58.72	49.46
Sulfosulfuron + Metsulfuron	32	392.2	365	36.3	30.59	38.6	38.67	45.50	43.20	65.08	61.20
Mesosulfuron + Iodosulfuron	14.4	377.6	336	33.7	27.71	36.5	36.70	38.76	34.15	55.48	49.17
Clodinafop + Metsulfuron	60+4	387.4	347	35.5	29.53	37.6	36.47	43.02	37.39	62.74	53.07
Isoproturon + 2,4-D	1000 + 500	369.6	316	31.3	26.77	36.4	34.77	35.43	29.38	51.29	41.78
Weedy check		314.9	285	29.4	23.32	35.8	33.63	29.21	22.32	42.81	31.68
Weed free		405.8	397	38.1	32.4	40.1	40.5	48.79	52.13	70.02	72.85
CD (P=0.05)		14.24	11.98	2.07	3.79	1.06	1.23	2.46	3.40	3.62	5.09

The mean data on weeds were subjected to square root transformation (√x+1) to normalize their distribution. The grain yield of wheat is adjusted at 14% moisture.

RESULTS AND DISCUSSION

Weed population and dry weight

The experimental field was infested with *Phalaris minor and Avena ludoviciana* among the grassy weeds. *Anagallis arvensis*, *Rumex maritimus, Medicago denticulata*, *Chenopodium album, Vicia sativa*, *Melilotus indica* and *Trachyspermum* spp. among the broad-leaved weeds (Table 1). The minor density of *Poa annua* and *Lathyrus aphaca*, *Fumaria parviflora* and *Cirsium arvense* also observed. The density of broad-leaved was higher than the grassy weeds. All the weed control treatments reduced the density of dry weight of weeds significantly than weedy check. The lowest weed density and dry matter of weeds was found with application of clodinafop+metribuzin (60+210 g/ha) which was significant over all the treatments but remained at par with sulfosulfuron+metsulfuron (32 g/ha) at 60 DAS in both the years and at 120 DAS in 2011-12 and pinoxaden+metribuzin (40+210 g/ha) in 2012-13 (Table 3). Similar results were reported earlier by Kumar *et al*. (2013). Also tank-mix application of pinoxaden with 2,4-D proved significantly effective in reducing density and dry weight of weeds than weedy check. Tank mixture of pinoxaden with 2,4-D did not result any antagonistic effect as anticipated. Hence, pinoxaden can safely be used as tank mix with 2,4-D, metsulfuron or carfentrazone with no loss of herbicide efficacy (Shoeran *et al.* 2013). Similarly, excellent control of complex weed flora in wheat was observed with the tank-mix application of clodinafop+metsulfuron-methyl (15:1 ratio) at 60 g/ha (Punia *et al.* 2004). The alone application of clodinafop 60 g/ha significantly reduced the weed density and dry weight than alone application of metribuzin 210 g/ha, pinoxaden 40 g/ha and sulfosulfuron 25 g/ha but these were significantly lower than weedy check. On the other hand, application of metribuzin 210 g/ha resulted in significantly lower population of weeds

Table 3 Effect of herbicides on weed density (No./m^2) and weed dry weight (g/m^2) at 60 DAS and 120 DAS in wheat crop

Treatment	Dose (g/ha)	Weed density at 60 DAS (No./m^2)		Weed density at 120 DAS (No./m^2)		Weed dry weight at 60 DAS (g/m^2)		Weed dry weight at 120 DAS (g/m^2)	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Metribuzin	210	5.70 (32.1)	6.68 (43.9)	7.19 (51.3)	7.01 (48.4)	6.82 (46.1)	6.79 (45.3)	9.47 (89.3)	7.26 (51.9)
Clodinafop	60	4.18 (17.2)	4.47 (19.1)	5.26 (27.4)	4.80 (22.1)	4.87 (23.3)	4.63 (20.5)	6.94 (48.0)	5.15 (25.7)
Pinoxaden	40	4.93 (23.9)	5.38 (28.1)	6.22 (38.3)	5.76 (32.4)	5.93 (34.7)	5.49 (29.4)	8.18 (66.5)	6.05 (35.7)
Sulfosulfuron	25	6.83 (46.4)	7.68 (58.4)	8.62 (74.4)	8.18 (66.1)	8.04 (64.5)	7.68 (58.6)	11.17 (124.9)	8.44 (70.4)
Clodinafop + Metribuzin	60 + 210	3.13 (9.4)	3.43 (11.0)	4.04 (15.9)	3.57 (11.9)	3.67 (13.1)	3.52 (11.6)	5.32 (28.1)	3.96 (14.9)
Pinoxaden + Metribuzin	40 + 210	4.20 (17.4)	3.75 (13.2)	5.34 (28.3)	4.22 (17.0)	4.92 (24.0)	3.85 (14.0)	7.04 (49.7)	4.56 (19.9)
Sulfosulfuron + Metribuzin	25 + 210	4.65 (21.4)	5.07 (24.8)	5.86 (34.3)	5.30 (27.1)	5.52 (30.2)	5.10 (25.1)	7.81 (61.3)	5.53 (29.7)
Fenoxaprop + Metribuzin	120 + 210	4.55 (20.3)	4.94 (23.5)	5.74 (32.5)	5.34 (27.6)	5.37 (28.4)	5.02 (24.3)	7.38 (54.3)	5.66 (31.1)
Sulfosulfuron + Metsulfuron	32+4	3.53 (12.0)	4.03 (15.4)	4.44 (19.4)	4.35 (17.9)	4.15 (16.8)	4.14 (16.3)	5.87 (34.1)	4.76 (21.7)
Mesosulfuron + Iodosulfuron	14.4	4.98 (24.5)	5.42 (28.5)	6.28 (39.2)	5.64 (31.0)	5.88 (34.3)	5.50 (29.4)	8.24 (68.2)	5.96 (34.7)
Clodinafop + Metsulfuron	60+4	4.23 (17.6)	4.56 (19.9)	5.32 (28.2)	4.68 (21.0)	4.98 (24.6)	4.66 (20.9)	6.99 (48.9)	5.03 (24.4)
Isoproturon + 2,4-D	1000 + 500	7.50 (56.0)	8.82 (77.1)	9.47 (89.5)	8.96 (79.5)	8.86 (78.4)	8.81 (76.8)	11.87 (141.0)	9.27 (85.2)
Weedy check		13.97 (194.8)	14.65 (213.7)	15.57 (242.2)	14.90 (221.1)	14.92 (222.2)	14.48 (208.8)	18.82 (353.7)	15.35 (234.7)
Weed free		1.00 (0.0)	1.00 (0.0)	2.23 (4.6)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	2.83 (7.7)	1.00 (0.0)
CD (P=0.05)		0.65	0.80	0.87	0.72	0.96	0.80	0.97	0.72

*Date were subjected to square root transformation, figures in parenthesis indicate original values.

than application of clodinafop 60 g/ha, pinoxaden 40 g/ha and sulfosulfuron 25 g/ha because it controlled grassy weeds more efficiently (Kumari *et al*. 2013). Singh *et al*. (2005) also reported that alone application of sulfosulfuron 25 g/ha or metribuzin 210 g/ha provided reduction in density of broad-leaf weeds. Significantly the highest weed density and dry matter of weeds were found with application sulfosulfuron 25 g/ha over alone application of clodinafop 60 g/ha, metribuzin 210 g/ha and pinoxaden 40 g/ha. Among the tank-mixed herbicides, isoproturon+2,4-D 1000+500 g/ha was found infective in controlling of weeds as compared to other tank-mixed herbicides. Accordingly, maximum weed control efficiency and lowest weed index were observed with clodinafop+metribuzin (60+210 g/ha) followed by sulfosulfuron+metsulfuron (32 g/ha) and pinoxaden+metribuzin (40+210 g/ha). These results are in conformity with Sharma (2012).

Yield attributes and yield of wheat

Weed control treatments had significant effect on earheads/m^2, grains/earhead, 1000 seed weight and grain yield of wheat in both the years (Table 2). The highest number of earheads/m^2 with tune of 406 and 397 was found with weed free which was statistically at par with clodinafop+metribuzin (60+210 g/ha), and pinoxaden+metribuzin (40+210 g/ha) in both the years and sulfosulfuron+metsulfuron (32 g/ha) in 2011-12 and significantly higher than other treatments as evident from the lower weeds dry matter in these herbicides. Among the herbicidal treatments, the clodinafop+metribuzin (60+210 g/ha) produced significantly higher earhead/m^2 than metribuzin 210 g/ha, sulfosulfuron 25 g/ha, pinoxaden 40 g/ha, mesosulfuron + idosulfuron 14.4 g/ha and isoproturon+2,4-D 1000+500g/ha in 2011-12 but in 2012-13 the maximum earhead/m^2 was recorded with pinoxaden+metribuzin (40+210 g/ha) which was at par with clodinafop+metribuzin (60+210 g/ha). A positive effect of herbicide mixtures in controlling complex weed flora have also been reported by Singh *et al*. (2005). All the weed control treatments produced significantly higher grains/earhead than weedy check with the exception of isoproturon+2,4-D 1000+500g/ha in both the years and sulfosulfuron 25 g/ha in 2012-13. The maximum grains/earhead was observed with weed free followed by clodinafop+metribuzin (60+210 g/ha). Similarly, all the weed control treatments produced higher test weight than weedy check. The highest grains/earhead was found in weed free followed by clodinafop+metribuzin (60+210 g/ha). This may be due to less competition for different resources in herbicide treatments being efficient in controlling weeds which resulted in more translocation of food from source to sink. Similar result had also been reported by Singh *et al*. (2012). The wheat grain reduced by 40.13 to 57.18% due to infestation of weeds. The reduction of weed density and dry weight of weeds in all the herbicidal treatments significantly increased the grain yield and straw yield of wheat over weedy check. The highest grain yield with tune of 48.79 and 52.13 q/ha was recorded with weed free which was significantly higher than all the other treatments except pinoxaden+metribuzin (40+210 g/ha) and clodinafop+metribuzin (60+210 g/ha) in 2011-12. Among the herbicidal treatments, the highest grain yield was found with clodinafop+metribuzin (60+210 g/ha) which was statistically at par with pinoxaden+metribuzin (40+210 g/ha) in both the years and sulfosulfuron+metsulfuron (32 g/ha) in 2012-13, which may be due to the better weed control as evident from the higher WCE as compared to other herbicides. Similar results have been documented by Singh *et al*. (2009), Kumar *et al*. (2013) and Singh *et al*. (2015). The alone application of clodinafop 60 g/ha significantly increased grain yield than alone application of metribuzin

Table 4 Weed index and weed control efficiency as influenced by different herbicides

Treatment	Dose (g/ha)	Weed index (%)		Weed control efficiency (%) at 60 DAS		Weed control efficiency (%) at 120 DAS	
		2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Metribuzin	210	20.68	41.17	79.27	78.30	74.76	77.89
Clodinafop	60	10.02	22.42	89.50	90.18	86.43	89.05
Pinoxaden	40	21.87	38.54	84.37	85.92	81.20	84.79
Sulfosulfuron	25	26.73	43.10	70.98	71.93	64.70	70.00
Clodinafop + Metribuzin	60 + 210	2.68	7.02	94.10	94.44	92.07	93.65
Pinoxaden + Metribuzin	40 + 210	4.12	11.66	89.18	93.30	85.96	91.52
Sulfosulfuron + Metribuzin	25 + 210	15.17	29.69	86.39	87.98	82.68	87.35
Fenoxaprop + Metribuzin	120 + 210	17.07	34.66	87.23	88.36	84.66	86.75
Sulfosulfuron + Metsulfuron	32	6.74	17.13	92.42	92.19	90.37	90.75
Mesosulfuron + Iodosulfuron	14.4	20.56	34.49	84.57	85.92	80.72	85.22
Clodinafop + Metsulfuron	60+4	11.83	28.28	88.91	89.99	86.18	89.60
Isoproturon + 2,4-D	1000 + 500	27.38	43.64	64.72	63.22	60.14	63.70
Weedy check		40.13	57.18	0.00	0.00	0.00	0.00
Weed free		0.00	0.00	100.00	100.00	97.82	100.00

Table 5 Correlation matrix of weed infestation and yield and yield attributes of wheat (based on mean of 2 years)

Parameters	Weed density at 120 DAS	Weed dry weight at 120 DAS (g/m^2)	Earheads /m^2	Grains/ earhead	Test weight (g)	Grain yield (q/ha)
Weed density at 120 DAS	1	0.99**	-0.860**	0.823**	0.697**	-0.784**
Weed dry weight at 120 DAS (g)		1	-0.870**	0.836**	0.715**	-0.799**
Earheads/m^2			1	0.978**	0.940**	0.983**
Grains/earhead				1	0.952**	0.990**
Test weight (g)					1	0.980**
Grain yield (q/ha)						1

210 g/ha, pinoxaden 40 g/ha and sulfosulfuron 25 g/ha. Among the herbicides, isoproturon+2,4-D 1000+500 g/ha gave significantly lowest grain yield than other herbicides except alone application of sulfosulfuron 25 g/ha, pinoxaden 40 g/ha and metribuzin 210 g/ha during both the years of study. The maximum straw yield was recorded with weed free was at par with clodinafop+metribuzin (60+210 g/ha) in both the years and pinoxaden+metribuzin (40+210 g/ha) in 2011-12. Moreover, rapid growth of wheat plant efficiently utilized the resources in absence of weeds. Similar result had also been reported by Kumari *et al*. (2013).

Correlation studies

All yield attributes of wheat have a significant positive correlation with grain yield but negative correlation with weed density and dry matter of weeds, with earheads/m^2 and grain yield (q/ha)(Table 5). The highest positive correlation was recorded between weed density and weed dry weight. Among the yield attributes, the highest positive correlation was found with grains/earhead followed by earheads/m^2 and grain yield. Number of earheads/m^2 and grain yield was negatively correlated with weed density and weed dry weight. The similar results were also reported by Kumar *et al*. (2010) and Bharat *et al*. (2012).

It was concluded that the pre-mixed application clodinafop+metribuzin (60+210 g/ha) followed by sulfosulfuron+metsulfuron (32 g/ha) and pinoxaden+ metribuzin (40+210 g/ha) gives higher yield and more weed control efficiency and lowest weed index than other treatments, thus these can be used to control of weeds in wheat.

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