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RESEARCH ARTICLE

Broad-leaved weed management in wheat through herbicide mixture in sub-tropical Shivalik Himalayan foothills

M.C. Dwivedi[1*], R. Puniya[2], Kanik Kumar Bansal[3] and Rakesh Kumar[3]

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ABSTRACT

Weed infestation is one of the major biotic factors limiting wheat production and productivity in absence of weed management practice. In order to control the broad-leaved weed infestation in wheat, the herbicides and their mixtures were tested in a field experiment under All India Coordinated Wheat and Barley Improvement Project, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, India during *Rabi* (winter) seasons of 2016-17 and 2017-18. Results showed that herbicide mixtures (broad-leaved weed killer) were found better in compared to alone application of broad-leaved weed herbicides. Among herbicide mixtures, application of metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha resulted in highest growth, yield attributes, grain yield and weed control efficiency and it was followed by 2,4-D E 500 g/ha + carfentrazone 20 g/ha. Hence, the highest net returns (₹ 72209 and ₹ 69762/ha) and B: C (2.81 and 2.60) were recorded by application of metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha.

Keywords: 2,4-D, Carfentrazone, Economics, Florasulam, Halauxifen-methyl, Wheat, Weed management

INTRODUCTION

In India, wheat a major staple food crop, provides a significant proportion of the daily calorie intake for millions of people. The mean national wheat yield consistently falls below its maximum achievable potential in numerous countries including the Indian subcontinent. Weeds are considered as a primary biotic impediment for achieving maximum wheat yield and are often the costliest inhibitory factor, contributing food insecurity. The magnitude of weed-induced losses in agricultural systems is influenced by several factors, including weed species, density, duration of infestation, crop competition, and prevailing climatic conditions (Kaur *et al.* 2021). To effectively manage a diverse and intricate array of weeds, it is often necessary to utilize different herbicides in combination. This practice not only enhances the overall efficacy of weed management against particularly challenging weed species, but it also serves to mitigate the development and onset of herbicide resistance, as evidenced by previous research (Singh *et al.* 2011). Recent findings have demonstrated that both broad-leaved and grassy weeds possess the potential to drastically curtail wheat grain production by as much as 40-52.2% and 55.7-57%, respectively (Pawar *et al.* 2017 and Chand and Puniya 2017). Another study conducted by Sharma *et al.* (2011) reported a significant reduction of 47.5% in wheat grain yield in the weedy check as compared to other treatments. In order to adequately address the complexities posed by such intricate and diverse weed populations, the use of a diverse range of herbicides is often necessary. As such combinations are typically more effective in terms of controlling composite weed populations and serve to delay the emergence of herbicide resistance (Shaktawat *et al.* 2019). In the context of wheat production, the efficacy and economic feasibility of novel herbicides need to be continually assessed to ensure their effectiveness, because the use of less efficacious herbicides is a critical bottleneck that hampers the productivity and profitability of conventional wheat farming in India.

The current investigation was carried out with the objective of identifying the most appropriate herbicide mixture to achieve optimal broad-leaved weed suppression in wheat, while simultaneously evaluating the economic feasibility of various herbicide options in relation to wheat productivity in the region.

[1] Research Farm, Directorate of Research, SKUAST-J, Chatha, Jammu, J&K 180009, India

[2] AICRP Weed Management, SKUAST-J, Chatha, Jammu, J&K 180009, India

[3] Division of Agronomy, SKUAST-J, Chatha, Jammu, J&K 180009, India

* Corresponding author email: drmaheshagron@gmail.com

MATERIALS AND METHODS

The present field experiment was carried out in All India Coordinated Wheat and Barley Improvement Project, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, located in the Union Territory of Jammu and Kashmir in the sub-tropical Shivalik Himalayan foothills in India during *Rabi* (winter) seasons of 2016-17 and 2017-18**.** The soil of the experimental field was clay loam in texture, slightly alkaline in reaction (pH 7.5), low in organic carbon (0.45%) and available nitrogen (171 kg/ha) but medium in phosphorus (14.4 kg/ha) and potassium (140 kg/ha). Total rainfall received during 2016-17 and 2017-18 was 264.2 and 80.8 mm, respectively.

The study employed a randomized block design (RBD) in three replication with 11 herbicide treatments, *viz*. halauxifen + florasulam 12.76 g/ha + 750 ml/ha surfactant, metsulfuron 4 g/ha + surfactant 625 ml/ha, carfentrazone 20 g/ha, 2,4-D Na 500 g/ha, 2,4-D E 500 g/ha, metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha, 2,4-D Na 500 g/ha + carfentrazone 20 g/ha, 2,4-D E 500 g/ha + carfentrazone 20 g/ha, halauxifen+ florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha, weedy check and weed free. Wheat variety "*HD 2967*" was sown with *Kera* method (seed is dropped in furrows by hand) in the first week of November during 2016 and 2017 at a row spacing of 20 cm using seed rate of 100 kg/ha. Before sowing, one pre-sowing irrigation was applied. All the herbicidal treatments were applied at 35 days after sowing by using a knapsack sprayer fitted with flat fan nozzle with spray volume of 500 L/ha. To control grassy weeds, a blanket spray of clodinafop propargyl 60 g/ha was given at 40 days after sowing in all the plots. The recommended dose of 150:60:40 kg/ha NPK was applied. Nitrogen was applied into three equal splits, one as basal dose along with the full dose of P and K, while the remaining two doses were applied at CRI and before booting stages. Crop was raised under irrigated condition.

Growth parameter (plant height), yield attributes (earhead/m^2, grains/earhead, test weight) and grain yield were recorded at harvest. The weed density, weed biomass and weed control efficiency of broad-leaved weeds were recorded at 60 and 90 days after sowing. Weed control efficiency (WCE) was 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. The mean data on weeds were subjected to square root transformation ($\sqrt{x+1}$) to normalize their distribution. The grain yield of wheat is adjusted at 14% moisture.

RESULTS AND DISCUSSION

Plant height

The highest plant height was observed with weed free which was statistically at par with all the treatments except weedy check during both the years (**Table 1**). The results of this study were in correspondence with the findings of Cheem and Akhter (2005) and Ali *et al*. (2022) who stated that the expression of plant height is more associated with inheritance than herbicidal treatments.

Earheads/m^2

Herbicides had a significant effect on earhead count per m^2 (**Table 1**). The highest number of ear heads counted per m^2 of wheat were observed with weed free during both years, which was statistically at par with treatments metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/h, 2,4-D Na 500 g/ha + carfentrazone 20 g/ha, 2,4-D E 500 g/ha + carfentrazone 20 g/ha and halauxifen + florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha. In these treatments, there was less competition due to better weed control leading to higher earhead per m^2. On the other hand, the lowest count of earheads/m^2 was observed in weedy check and among herbicidal treatments, 2,4-D Na 500 g/ha recorded the lowest count of ear heads/m^2 during both years of experiment.

Number of grains per earhead

The highest number of grains per ear head was observed under metsulfuron 4 g/ha + surfactant 625 ml/ha and halauxifen + florasulam 12.76 g/ha during 2016-17 and 2017-18, respectively, although not affected significantly (**Table 1**).

Test weight

The grain weight is an important factor that affects the quality and value of crops. The highest grain weight was recorded with weed free treatment. Among herbicidal treatments, the highest grain weight was attained by metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha during 2016-17 and halauxifen+ florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha during 2017-18.

Grain yield

The grain yield is the net product of all the yield attributes and environmental conditions. The grain yield in weedy check was reduced by 32.96 and 29.69% during 2016-17 and 2017-18, respectively as compared to weed free treatment (**Table 1**). All the weed control treatments recorded significantly higher grain yield than weedy check treatment. The highest grain yield reordered in weed free treatment was statistically at par with metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha, 2,4-D Na 500 g/ha + carfentrazone 20 g/ha, 2,4-D E 500 g/ha + carfentrazone 20 g/ha and halauxifen+ florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha during both the years, whereas treatment carfentrazone 20 g/ha was also statistically at par during 2017-18. The herbicidal treatment, metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/h recorded 148.0 and 138.2% higher grain yield than weedy check but had 0.7 and 2.9% less than weed-free treatment during 2016-17 and 2017-18, respectively. Mitra *et al.* (2019) and Ram and Kaur (2020) also reported similar results and concluded that better weed control helped the crop to attain better yield attributes resulting in better grain yield.

Broad-leaved weed density and biomass

The experimental field was infested with broad-leaved weeds namely, *Anagallis arvensis*, *Rumex maritimus, Medicago denticulata*, *Chenopodium album*, *Vicia sativa*, *Melilotus indica*, *Lathyrus aphaca*, *Fumaria parviflora, Cirsium arvense* and *Trachyspermum* spp. The weed density and biomass recorded at 60 and 90 days after sowing were highest in weedy check and were significantly higher than all the herbicidal treatments during both years of experiment (**Table 2**). Among the herbicidal treatments, the lowest weed density and biomass at 60 and 90 days after sowing were recorded in treatment metsulfuron + carfentrazone + surfactant and 2,4-D E 500 g/ha + carfentrazone 20 g/ha, respectively and these treatments were statistically at par to each other during both years of experimentation. Weed density in the best herbicidal treatment of metsulfuron + carfentrazone + surfactant was 94.0 - 95.7% less as compared to the weedy check. The herbicide mixture was more effective in controlling the weeds. The lower weed biomass recorded in herbicide mixture treatments was due to better weed control as the weed density was low in these treatments. Chhokar *et al.* (2015) and Ram and Kaur (2020) also reported that pre-mix formulation of metsulfuron + carfentrazone + surfactant was more effective in controlling broad-leaved weeds.

Weed control efficiency

The weed control efficiency depicts the comparative performance of the herbicides. The higher weed control efficiency was recorded in treatment 2,4-D E 500 g/ha + carfentrazone 20 g/ha followed by treatment metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha during 60 days after sowing but at 90 days after sowing metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha performed better than treatment 2,4-D E 500 g/ha + carfentrazone 20 g/ha (**Table 2**). It was due to better diverse broad-leaved weed control in these treatments. Singh *et al.* (2011) also reported effectiveness of pre-mix carfentrazone + metsulfuron for broad-leaved weed control in wheat. The weed control efficiency recorded in 2,4-D (ethyl ester) + carfentrazone was the highest, however, it was almost similar to 2,4-D (Na salt) + carfentrazone, metsulfuron + carfentrazone + surfactant and carfentrazone alone.

Table 1. Effect of weed control treatments on plant height, yield attributes, grain yield of wheat

Treatment	Plant height (cm)		Ear head/m^2		Grains/ ear head		Test weight (g)		Grain yield (t/ha)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Halauxifen + florasulam 12.76 g/ha	82.3	84.1	366.7	369.0	31.7	33.6	36.4	35.6	4.18	4.40
Metsulfuron 4 g/ha + surfactant 625 ml/ha	84.1	85.7	376.7	378.7	32.3	30.4	36.7	37.8	4.46	4.31
Carfentrazone 20 g/ha	86.6	88.2	377.7	375.7	31.3	34.5	36.9	35.4	4.31	4.56
2,4-D Na 500 g/ha	83.5	84.1	360.0	362.3	31.1	31.4	36.6	37.2	4.10	4.22
2,4-D E 500 g/ha	82.4	84.7	370.0	374.0	31.5	31.8	36.9	37.3	4.27	4.39
Metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha	86.2	88.6	431.7	428.3	31.3	31.1	38.0	37.3	5.09	4.89
2,4-D Na 500 g/ha + carfentrazone 20 g/ha	89.1	90.2	415.0	422.0	30.5	30.1	37.9	36.7	4.81	4.67
2,4-D E 500 g/ha + carfentrazone 20 g/ha	90.1	89.9	411.7	416.3	32.2	30.3	37.8	38.1	4.97	4.80
Halauxifen + florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	88.1	87.5	407.3	410.3	31.2	28.9	37.5	38.5	4.74	4.56
Weedy check	74.9	73.3	316.7	326.3	31.4	32.9	34.9	33.4	3.44	3.54
Weed free	90.4	90.2	435.0	440.3	31.0	29.4	38.1	39.0	5.13	5.03
LSD (p=0.05)	10.0	8.5	51.9	49.4	NS	NS	NS	NS	0.49	0.52

Economics

The weeds cause the loss in gross returns, net returns and B: C. Gharde *et al*. (2018) also recorded significant economic loses in wheat due to weeds. The highest gross returns were recorded in weed-free treatment but net returns and B:C were the highest under treatment metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha (**Table 3**). It was due to higher grain yield and less cost of cultivation than weed free treatment. Among herbicidal treatments, the highest gross returns were recorded in treatment metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha followed by 2,4-D E 500 g/ha + carfentrazone 20 g/ha and 2,4-D Na 500 g/ha + carfentrazone 20 g/ha. Treatment, metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha recorded 5.9 and 2.9 per cent higher net return than weed free and 72.0 and 56.6 per cent higher than weedy check, and recorded 26.0, and 21.4 per cent higher B:C ratio than weed free and 62.4 and 47.7 per cent higher than weedy check during 2016-17 and 2017-2018, respectively. It was due to higher weed control efficiency and grain yield in this treatment. Nekhat *et al*. (2020) and Ram and Kaur (2020) also reported similar results and concluded that better weed control helped to attain better profitability.

Conclusion

Based on two years field experimentation, it was concluded that among various herbicide treatments, the mixed application of herbicides was better than alone application. Among herbicide mixtures, metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha was found the most effective against broad-leaved weeds in wheat and gave higher weed control efficiency, net return and B: C. Therefore, mixture of metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha can be used in wheat crop to control broad-leaved weeds.

Table 2. Effect of weed control treatments on weed density, weed of biomass and weed control efficiency in wheat

Treatment	Weed density of broad-leaved(no./m^2)				Biomass of broad-leaved weeds(g/m^2)					
	60 DAS		90 DAS		60 DAS			90 DAS		
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	Mean WCE	2016-17	2017-18	Mean WCE
Halauxifen+ florasulam 12.76 g/ha	5.51(29)	5.20(26)	5.92(34)	6.11(36)	7.32(53)	6.50(41)	75.00	8.42(70)	7.3 1(52)	77.59
Metsulfuron 4 g/ha + surfactant 625 ml/ha	3.96(15)	4.28(17)	4.40(18)	4.65(21)	5.21(26)	5.03(24)	86.59	6.24(38)	6.31(39)	86.00
Carfentrazone 20 g/ha	4.20(17)	4.55(20)	4.58(20)	5.20(26)	5.62(31)	5.43(28)	84.29	6.43(40)	6.36(40)	85.44
2,4-D Na 500 g/ha	5.66(31)	5.77(32)	5.89(34)	5.86(33)	7.47(55)	6.62(43)	73.97	8.33(68)	7.64(57)	77.00
2,4-D E 500 g/ha	4.16(16)	4.24(17)	4.20(17)	4.51(19)	5.47(29)	5.59(30)	84.29	5.88(34)	6.15(37)	87.17
Metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	2.38(5)	2.83(7)	2.58(6)	2.83(7)	3.06(8)	3.42(11)	94.94	3.64(12)	3.85(14)	95.25
2,4-D Na 500 g/ha + carfentrazone 20 g/ha	3.00(8)	3.16(9)	3.21(9)	3.51(11)	3.90(14)	4.14(16)	91.94	4.59(20)	4.57(20)	92.72
2,4-D E 500 g/ha + carfentrazone 20 g/ha	2.45(5)	2.65(6)	2.77(7)	3.11(9)	3.14(9)	3.33(10)	94.97	3.92(14)	4.22(17)	94.33
Halauxifen + florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	3.16(9)	2.83(7)	3.46(11)	3.65(12)	4.14(16)	4.46(19)	90.71	4.86(23)	4.91(23)	91.66
Weedy check	10.5(109)	10.8(116)	11.5(131)	11.8(138)	13.6(184)	13.9(192)	0.00	16.4(267)	16.8(282)	0.00
Weed free	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	100.00	1.00(0)	1.00(0)	100.00
LSD (p=0.05)	0.43	0.53	0.40	0.61	0.59	0.55	-	0.64	0.62	-

Data in parentheses are original values. Note: All herbicides were applied at 35 days after sowing; A blanket application of clodinafop 60 g/ha at 40 days after sowing was common for all plots.

Table 3. Effect of weed control treatments on economics of wheat crop

Treatment	Cost of cultivation ($x10^3$ `/ha)		Gross returns ($x10^3$ `/ha)		Net returns ($x10^3$ `/ha)		B: C ratio (`/ha)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Halauxifen+ florasulam 12.76 g/ha	26.18	27.28	80.41	86.86	54.23	59.58	2.07	2.18
Metsulfuron 4 g/ha + surfactant 625 ml/ha	24.76	25.86	85.85	85.12	61.10	59.26	2.47	2.29
Carfentrazone 20 g/ha	25.16	26.26	83.02	89.98	57.87	63.72	2.30	2.43
2,4-D Na 500 g/ha	25.65	26.75	78.87	83.40	53.22	56.65	2.07	2.12
2,4-D E 500 g/ha	25.52	26.62	82.14	86.64	56.62	60.02	2.22	2.26
Metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	25.72	26.82	97.92	96.58	72.21	69.76	2.81	2.60
2,4-D Na 500 g/ha + carfentrazone 20 g/ha	26.61	27.71	92.53	92.33	65.93	64.62	2.48	2.33
2,4-D E 500 g/ha + carfentrazone 20 g/ha	26.48	27.58	95.67	94.74	69.20	67.16	2.61	2.44
Halauxifen+ florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	27.13	28.23	91.19	90.10	64.05	61.87	2.36	2.19
Weedy check	24.20	25.30	66.16	69.89	41.96	44.59	1.73	1.76
Weed free	30.56	31.66	98.69	99.42	68.13	67.76	2.23	2.14

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