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Research Paper

Efficacy of herbicides and their impact on the productivity, energy relationships and economics of wheat (*Triticum aestivum*) in Vertisols of Central India

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ABSTRACT

Field experiment was conducted at Research Farm of Indore, Madhya Pradesh during the winter (*rabi*) season of 2016–17 and 2017–18, to find out the efficacy of different post-emergence herbicides (halauxifen-methyl-ester, 2, 4-D and metsulfuron methyl) alone as well as mixture with carfentrazone for the control of broad-leaf weeds in wheat (*Triticum aestivum* L.). Data on weed dynamics indicated that, weed density and weed dry weight for broad-leaf weeds decreased significantly with these herbicides as compared to weedy check. However, the maximum reduction was observed with an application of halauxifen @ 12.76 g/ha and this treatment also recorded the highest values of weed-control efficiency and the lowest values of weed index. Application of carfentrazone as sole or in combination resulted in the phyto-toxicity while higher leaf burning was observed when applied with metsulfuron and halauxifen. The maximum grain yield (6.60 and 6.27 t/ha) and biological yield (15.24 and 14.67 t/ha) were recorded with weed-free environment, being at par with application of halauxifen and metsulfuron and these treatments were altogether significant over the weedy check. Growth and yield attributes also followed the similar trend to that of grain yield. Although the highest values of energy input (23.32 thousand MJ/ha), energy output (₹201.1 thousand MJ/ha), cost of cultivation (52.4 thousand/ha) and gross returns (₹142.4 thousand/ha) were estimated with weed-free treatment, but application of halauxifen resulted in the maximum energy ratio (8.72), energy productivity (279.8 g/MJ), net returns (₹92.8 thousand/ha) and benefit: cost ratio (2.99). Thus, post-emergence application of halauxifen- methyl-ester @ 12.76 g/ha or metsulfuron methyl @ 4 g/ha found effective in controlling of broad-leaf weeds and fetched higher net returns and energy productivity of wheat in Vertisols of Central India.

Key words : Broad-leaf weeds, Economics, Energy relationships, Herbicides, Grain yield, Weed dynamics, Wheat

Wheat (*Triticum aestivum* L.) is an important food crop in many countries across the globe and widely grown in almost all parts of India. It is the backbone of food security in the country, contributing around 40% of the foodgrain production. Due to burgeoning population and demand for food, yield maximization is quite imperative and the production target set to meet the ever-increasing demand of staple food such as wheat and wheat products of Indian population to the tune of 140 million tonnes (mt) by 2050 (ICAR-IIWBR, 2019). Such target can only be achieved by improving the level of crop productivity across the regions with a little or no scope for area expansion due to great pressure on land for other commercial crops. However, maintaining this productivity and production to the required level is a big challenge due to change in climate and increased biotic and abiotic stresses. Amongst the biotic stresses, the worldwide estimated yield loss caused by weeds varied between 7.7 and 23.9%, depending on the region (Oerke, 2006). However, in wheat crop productivity due to uncontrolled weeds may reduce grain yield to the tune of 15–40%, depending on magnitude, nature and duration of weed infestation (Jat *et al.,* 2003). In Central Zone of India, predominant broad-leaf weeds are: common lambsquarter (*Chenopodium album* L.), Indian sweet clover (*Melilotus indica*), *Hirankhuri* (*Convolvulus arvensis*), toothed bur clover (*Medicago hispida*), *Jangali palak* (*Rumex dentatus*), *Piajee* (*Asphodelus tenuifolius*), White *senji* (*Melilotus alba*), *Gajari* (*Fumaria parviflora*) etc. These weeds associated with wheat and pose competition for resources like nutrients, water, light, causing reduction in wheat yield and impairs the quality of produce. Hence, timely and efficient control of weeds in wheat is of paramount importance to optimize its productivity. Amongst

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weed-control methods, manual weeding has been a weed-management practice since centuries together due to availability of labour and the nature of agriculture as main occupation. Thus, a manual and mechanical methods have been the prevalent weed- management techniques adopted by farmers until the end of 1990s. Onwards, the farm wages increased leap and bounds resulting in concomitant reliance on herbicides either alone or as a component of integrated weed management (Rao *et al.*, 2014). Now-a-days chemical weed-control is gaining popularity. In this direction, Singh (2013) opined herbicides as the most successful weed-control technology, being selective in nature, cost-effective and relatively easy to apply. Herbicides are also eco-friendly if applied at proper dose, method and time, besides being quite safer in comparison to other pesticides. There are many promising herbicides for controlling broad-leaf weeds in wheat crop, the major herbicides used in India are metsulfuron, 2, 4-D and carfentrazone (Chhokar *et al.,* 2007). Amongst these 2, 4-D has been used for a long time and could be sensitive to some cultivar leading to yield reduction due to malformation (Pinthus and Natowitz, 1967; Balyan and Panwar, 1997) and as a result now it is less preferred by wheat growers. Generally, a herbicide is more effective against some of the weeds and less or not effective against others. Metsulfuron and 2, 4-D are ineffective against *Malwa parviflora* (Chhokar and Malik*,* 2002) and *Solanum nigrum* (Mukherjee *et al.,* 2011). Hence, a new herbicide such as carfentrazone has been recommended for the control of broad-leaf weeds having very fast action in controlling weeds like *Malva* spp. and *S. nigrum*. Also, some of the post-emergent contact herbicides like carfentrazone-ethyl are less effective on weeds having advanced stage, as well as, unable to control the subsequent weeds emerging after application due to its lack of residual activity (half life of carfentrazone is 2–5 days) in soil (Lyon *et al.,* 2007; Willis *et al.*, 2007). With this background, evaluation of herbicide alone and in combination become imperative to study in order to control the diverse infestation of broad-leaf weeds. Since, information on the conjoint use of herbicide is meager, present investigation was undertaken to assess the efficacy of different herbicides and their mixtures on controlling broad-leaf weeds in wheat to achieve higher productivity.

MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi*) season of 2016–17 and 2017–18 at Research Farm of the ICAR-Indian Agricultural Research Institute, Regional Station, Indore, Madhya Pradesh. The experimental site is located at 22.37°N and 75.50°E with a 557 m above mean sea-level and has semi-arid tropical climate, with mean annual rainfall of 758 mm. The soil was a deep Vertisols (Typic Haplustert) with clayey texture (52% clay) and bulk density of 1.34 Mg/m^3, having pH value 8.1, electrical conductivity 0.33 dS/m (1 : 2, soil: water ratio), medium in organic carbon (0.52%), available N (258.5 kg/ha) and available P (13.2 kg/ha), and high in available K (448.5 kg/ha). The experiment comprises of 11 treatments, viz. halauxifen-methyl-ester + florasulam 40.85% WG + polyglycol 26–2 N @ 12.76 g/ha (W_1), metsulfuron methyl + surfactant @ 4 g/ha (W_2), carfentrazone ethyl @ 20 g/ha (W_3), 2, 4-D Na (80 WP) @ 500 g/ha (W_4), 2, 4-D E 38 EC @ 500 g/ha (W_5), metsulfuron + carfentrazone @ 4 + 20 g/ha (W_6), 2,4-D Na + carfentrazone @ 400 + 20 g/ha (W_7), 2,4-D E + carfentrazone @ 400 + 20 g/ha (W_8), halauxifen + carfentrazone @ 10.21 g + 20 g/ha (W_9), weedy check (W_{10}) and weed-free (W_{11}) in randomized block design with 3 replications. The seed of wheat (cv. 'HI 1544') was sown 20.0 cm apart (row to row) on 9th and 12th November, and harvested on 8th and 5th April in 2016–17 and 2017–18, respectively. Recommended dose of N, P and K (120, 60 and 40 kg/ha) was applied basal, i.e. 50% N and full dose of P and K and remaining N dose in 2 equal splits as top-dressing through urea after first and second irrigations in both the years. Herbicides were sprayed at 4 week-crop stage, using a spray volume of 600 liters/ha with a knapsack sprayer fitted with flat-fan nozzle. The crop was raised under irrigated conditions and the recommended packages of practices were followed during the season. A uniform post-emergence spray of pinoxaden @ 40 g/ha was done in all the plots including the control for the control of narrow-leaf weeds. Data on weed count and weed dry weight from an area enclosed in a quadrate of 1.0 m^2 at 2 places from each plot were recorded at 30 and 60 days, and 60 and 90 days after spray, respectively. Data on weed density and dry weights were subjected to square-root transformation ($\sqrt{x + 0.5}$). Weed-control efficiency and weed index were computed as per standard formula. Phyto-toxicity was observed at 0 to 10 scales, where 0 as no-toxicity to 10 as highest (100%) phyto-toxicity level in affected plot. Weed-control efficiency (WCE) and weed index (WI) were calculated as per standard methods.

Data on yield attributes and yield of wheat were recorded at the time of harvesting. Mean comparisons of the treatments were made by the standard statistical method, as suggested by Gomez and Gomez (1984). Energy inputs and outputs were calculated using the energy equivalents, viz. manpower 1.96 MJ/hour, dry fodder 18 MJ/kg, nitrogen 60.6 MJ/kg, P_2O_5 11.1 MJ/kg, K_2O 6.7 MJ/kg etc. as suggested by Panesar and Bhatnagar (1987) and Devasenapathy *et al.* (2009). Economics was worked out on the basis of prevalent market prices of inputs and outputs.

RESULTS AND DISCUSSION

Weed density and dry weight

Composition of weed species (%) before spray in the control plots during 2016–17 was 42.9% lambsquarter (*Chenopodium album* L.), 10.6% toothed dock (*Rumex dentatus* L.), 10.1% yellow-flowered clover (*Melilotus indicus*), 7.4% carrot-grass (*Parthenium hystrophorus* L.), 5.8% field bindweed (*Convolvulus arvensis* L.), 2.3% small canary grass (*Phalaris minor* Retz.) and (20.9%) other weed species. However, during 2017-18 these predominant weeds were 43.4% *Chenopodium album,* 9.2% white sweet clover (*Melilotus alba* L.), 7.4% *Asphodelus tenuifolius*, 6.8% wild oat *(Avena sterilis* L.), 5.6% Indian fumitory (*Fumaria parviflora* Lam.), 3.4% *Phalaris minor*, 1.8% *Convolvulus arvensis* and 22.4% other species.

Data on weed dynamics indicated that all herbicides significantly decreased the weed density and weed dry weight/m^2 compared with weedy check at both the stages, i.e. weed density at 30 and 60 days after spray (DAS) and weed dry weight at 60 and 90 days after spray (DAS) in both the years (Table 1). Amongst herbicides, spray of halauxifen @ 12.76 g/ha was found most effective and recorded the highest reduction in weed population and weed dry weight in both the years except weed density at 30 and 60 DAS in the first year, where spray of metsulfuron at 30 DAS and 2, 4 DE + carfentrazone at 60 DAS recorded the lowest values. Variation in reduction in weed numbers and dry weight due to different herbicides might be due to differential selectivity towards broad-leaf weeds. Chhokar *et al.* (2015) also reported that, halauxifen @ 12.76 g/ha, metsulfuron 4 g/ha and metsulfuron + carfentrazone 4 + 20 g/ha gave effective control of broad-leaf weeds in wheat.

Weed-control efficiency and weed index

The maximum weed-control efficiency (WCE) was obtained with the application of halauxifen at 30 and 60 days after sowing (DAS) in both the years, except WCE recorded at 30 DAS in the first year, where conjoint use of halauxifen + carfentrazone was found highest (92.5%). Amongst herbicides alone or as mixture, application of carfentrazone @ 20 g/ha showed the lowest values of WCE at both the stages in both the years. In case of weed index (WI), application of halauxifen again recorded the lowest values of 2.12 and 1.91% in the first and the second year, respectively, and these values were followed by application of metsulfuron in both the years (Table 1). Application of carfentrazone recorded substantially higher values of WI due to its phyto-toxicity on wheat crop, which resulted in reduction in wheat yield and higher the values of WI as compared to weed-free and other weedicide-used plots. Kamboj *et al*. (2017) reported that application of carfentrazone + metsulfuron significantly reduced the population and dry-matter accumulation of all broad-leaf weeds with more than 95% WCE.

Phyto-toxicity

Observation on phyto-toxicity due to spray of carfentrazone as alone or as in combination with other chemicals were recorded on the scale of 0 to 10 (0 means no effect and 10 means 100% plants affected) showed that despite satisfactory control of multiple broad-leaf weeds with application of carfentrazone @ 20 g/ha recorded phyto-toxicity of different strength in both the years. Maximum phytotoxicity was observed with metsulfuron + carfentrazone, followed by halauxifen + carfentrazone. The strength of phyto-toxicity of carfentrazone was less when used as sole or along with 2, 4-DE or 2, 4-D Na. It indicates that carfentrazone @ 20 g/ha was found harmful in wheat crop grown in vertisols and it was more aggressive when such dose was mixed with other herbicides, especially with halauxifen and metsulfuron due to poor compatibility of carfentrazone with other herbicides which led to phytotoxicity.

Wheat yield attributes and yield

Yield attributes, viz. ears/m^2, grains/ear and 1,000-grain weight (g) showed non-significant difference except grains/ear during 2016–17 (Table 2). In case of grain and biological yields, weed-free treatment resulted in the highest wheat grain yields (6.60 and 6.27 t/ha) in both the years (Table 2). These yields being at par with halauxifen and metsulfuron application were significantly higher over rest of the treatments with minimum under weedy check (5.61 and 5.47 t/ha). The magnitude of increase of grain yield under weed free treatment was to the tune of 2.12 and 1.91% with halauxifen and 2.73 and 5.26% with metsulfuron application during 2016–17 and 2017–18 respectively. But with regards to biological yields, highest yields observed (15.24 and 14.67 t/ha) under weed-free treatment were at par with halauxifen; metsulfuron; 2, 4-DE*;* 2, 4-DE + carfentrazone and halauxifen methyl + cafentrazone in the first year and 2, 4-DE and 2, 4-DE + carfentrazone in the second year, but significantly higher over all the other treatments. Carfentrazone application alone as well as mixed with other herbicides decreased the values of crop yields due to its phyto-toxic effect on wheat crop except 2, 4-DE + carfentrazone during 2016–17 and 2, 4-DNa + carfentrazone in both the years, where despite of phyto-toxicity, wheat grain yields were improved as compared to their sole chemicals. However, in case of biological yields, not only carfentrazone alone application recorded lowest values of biological yields in both the years, but also decreased the biological yields of all when made conjoint use with other herbicides. Higher grain and bio-

Table 1. Effect of weed-management practices on weed density, dry weight, weed-control, weed index and phyto-toxicity in wheat

Treatment	Doses (g/ha)	Weed density*/m²				Weed dry weight* (g/m²)				Weed control efficiency (%)				Weed Index (%)		Phyto-toxicity*	
		2016-17		2017-18		2016-17		2017-18		2016-17		2017-18		2016-17	2017-18	2016-17	2017-18
		30 DAS	60 DAS	30 DAS	60 DAS	60 DAS	90 DAS	60 DAS	90 DAS	30 DAS	60 DAS	30 DAS	60 DAS				
Halauxifen-methyl ester	12.76	6.55 (42.5)	2.72 (7.0)	3.19 (10.2)	2.29 (5.00)	1.46 (1.64)	1.58 (2.02)	1.80 (2.76)	1.33 (1.32)	80.4	95.8	94.6	96.6	2.12	1.91	0	0
Metsulfuron methyl	4.0	5.76 (32.8)	3.93 (15.0)	4.00 (15.7)	2.96 (8.33)	2.00 (3.50)	2.47 (5.63)	2.01 (3.62)	1.71 (2.28)	84.9	91.1	91.7	94.3	2.73	5.10	0	0
Carfentrazone	20	8.60 (73.7)	7.16 (50.8)	4.85 (23.3)	4.29 (18.5)	3.24 (10.1)	3.16 (9.51)	2.71 (8.76)	3.10 (9.16)	66.0	69.9	87.6	87.3	10.0	16.1	1.33	0.75
2,4-D Na (80 WP)	500	7.67 (58.5)	6.41 (41.0)	4.03 (16.2)	3.55 (12.2)	2.94 (8.26)	2.88 (7.86)	2.03 (3.68)	3.08 (9.01)	72.9	75.7	91.4	91.6	6.36	9.09	0	0
2,4-D E 38 EC	500	5.99 (35.5)	3.90 (14.8)	3.83 (14.3)	2.87 (8.20)	1.86 (2.98)	2.15 (4.16)	1.96 (3.37)	1.61 (2.10)	83.6	91.2	92.4	94.4	3.03	6.22	0	0
Metsulfuron + carfentrazone	4+20	6.93 (47.7)	3.83 (14.3)	3.93 (15.2)	2.91 (8.20)	1.81 (2.79)	1.48 (1.73)	2.25 (4.71)	1.58 (1.99)	78.0	91.5	91.9	94.4	3.48	7.18	8.33	6.83
2, 4-D Na + Carfentrazone	400+20	6.28 (39.2)	5.09 (25.7)	5.40 (29.8)	3.63 (13.0)	2.26 (4.69)	2.14 (4.12)	2.51 (5.86)	1.72 (2.50)	81.9	84.8	84.2	91.1	6.97	10.4	1.0	2.50
2, 4-D E + Carfentrazone	400+20	6.23 (38.7)	2.31 (4.8)	3.73 (13.7)	2.81 (7.5)	1.48 (1.71)	1.59 (2.06)	2.09 (3.97)	1.70 (2.40)	82.1	97.1	92.7	94.8	3.48	10.2	1.33	1.77
Halauxifen methyl + carfentrazone	10.21+20	6.02 (35.8)	4.07 (16.2)	3.23 (10.2)	2.61 (6.5)	1.90 (3.12)	1.47 (1.67)	1.96 (3.42)	1.31 (1.24)	92.5	90.4	94.6	95.5	13.03	9.09	7.67	6.17
Weedy check	-	14.73 (216.8)	12.98 (168.7)	13.72 (188.7)	12.80 (145.8)	6.62 (44.0)	6.66 (44.3)	8.40 (70.5)	8.04 (64.4)	0	0	0	0	15.0	12.7	0	0
Weed-free	-	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	-	-	-	-	0	0	0	0
SEm±	-	0.36	0.31	0.50	0.38	0.20	0.15	0.21	0.15	-	-	-	-	-	-	-	-
CD (P=0.05)	-	1.06	0.92	1.46	1.09	0.59	0.45	0.62	0.43	-	-	-	-	-	-	-	-

*Figures are transformed values $\sqrt{x + 0.5}$ and values in parentheses are actual figures. **DAS, Days after spaym and *Phyto-toxicity recorded on 0–10 scale, where 0 means nil toxicity and 10 means full plot population toxicity

Table 2. Effect of weed-management practices on yield and yield attributes of wheat

Treatment	Doses (g/ha)	Ears/m^2		Grains/ear		1,000-grain weight (g)		Grain yield (t/ha)		Biological yield (t/ha)		Harvest index	
		2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Halauxifen-methyl ester	12.76	421.7	370.0	36.5	36.3	42.0	45.8	6.46	6.15	14.93	13.69	43.3	41.2
Metsulfuron methyl	4.0	420.8	362.5	35.8	36.3	42.7	45.6	6.42	5.94	15.13	13.57	42.4	43.8
Carfentrazone	20	404.2	363.3	34.3	31.4	42.6	46.1	5.94	5.26	13.90	12.29	42.7	42.8
2, 4-D Na (80 WP)	500	415.8	340.0	35.2	36.0	42.5	46.7	6.18	5.70	14.24	13.60	43.4	41.9
2, 4-D E 38 EC	500	410.0	362.5	36.5	35.5	42.8	46.5	6.40	5.88	15.00	14.06	42.7	41.8
Metsulfuron + carfentrazone	4+20	432.5	356.7	34.7	35.7	42.5	45.8	6.37	5.82	14.89	12.83	42.8	45.4
2, 4-D Na + carfentrazone	400+20	412.5	352.5	35.0	34.5	42.5	46.2	6.14	5.62	14.18	13.09	43.3	42.9
2, 4-D E + carfentrazone	400+20	398.7	362.5	37.3	34.5	43.0	45.1	6.37	5.63	14.65	13.86	43.5	40.6
Halauxifen methyl + carfentrazone	10.21+20	401.7	370.0	33.3	33.9	43.0	45.7	5.74	5.70	14.80	13.44	38.8	42.4
Weedy check	-	406.8	365.0	32.5	32.5	42.5	46.3	5.61	5.47	13.88	13.44	40.4	40.7
Weed-free	-	423.2	382.5	37.0	35.5	42.2	46.2	6.60	6.27	15.24	14.67	43.3	42.7
SEm±	-	8.14	14.0	0.92	1.68	0.43	0.35	0.06	0.14	0.22	0.33	-	-
CD (P=0.05)	-	NS	NS	2.71	NS	NS	NS	0.19	0.42	0.66	0.96	-	-

logical yields with the application of herbicide, viz. halauxifen, metsulfuron, 2, 4-D and under weed-free treatments might be owing to control of weeds, which increased the availability of nutrients, space and light to the plant by decreasing crop weed-competition. Chhokar *et al.* (2015) reported the maximum wheat yield under application of metsulfuron + carfentrazone @ 4 + 20 g/ha as it effectively controlled broadleaved weeds in wheat.

Energy relationships

Computation of energy in terms of energy input, energy output, energy ratio and energy productivity showed difference in energy-input values under different treatments due to varied levels of input and output energy was because of difference in values of produce that is grain and straw (Table 3). Because of comparatively higher consumption of energy on frequent weeding under weed-free treatment than herbicidal weed control, the maximum value of energy input was observed with weed-free treatment. Similarly, the maximum energy ratio (8.72) and energy productivity (279.8 g grain/MJ) were registered with halauxifen methyl, followed by energy ratio by 2, 4-DE (8.63) and energy productivity (276.0 g grain/MJ) by weed-free treatment. Higher values of energy ratio and energy productivity with the application of halauxifen was the function of almost similar wheat yields and proportionately lower increase in consumption of energy input. In spite of higher yield of wheat under weed-free treatment it could not record maximum values of energy ratio due to higher usage of energy input. The carfentrazone application either alone or mixed with other herbicides substantially decreased the energy output values of different treatments, and among herbicidal treatments less differences in energy input values further become responsible for decreasing the values of energy ratios and energy productivity.

Economics

Economics in terms of net returns and benefit: cost ratio on the basis of wheat yields and prevalent market prices of inputs and outputs showed that, an application of halauxifen @ 12.76 g/ha recorded the maximum net returns (₹92,800/ha) and benefit: cost (B: C) ratio (2.99), followed by metsulfuron @ 4 g/ha (90,300/ha and 2.94). Further, net returns and B:C ratio recorded with the application of herbicide 2, 4-DE (₹90,100/ha and 2.93) were substantially higher over rest of the treatments including weed-free treatments. Application of carfentrazone sole @ 20 g/ha greatly decreased the values of net returns (₹77,700/ha) and B: C ratio (2.67) due to lower wheat yields and almost similar or more expenditure on treatment imposition. On the contrary, less values of net return and B:C ratio under weed free treatment as compared to use of chemicals

Table 3. Effect of weed management practices on energy relationships and economics in wheat crop

Treatment	Doses (g/ha)	Energy Relationships				Economics			
		Energy input ($\times 10^3$ MJ/ha)	Energy output ($\times 10^3$ MJ/ha)	Energy ratio (or energy efficiency)	Energy productivity (grain in g/MJ)	Cost of cultivation ($\times 10^3$ ₹/ha)	Gross returns ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Benefit: cost ratio
Halauxifen-methyl ester	12.76	22.53	196.5	8.72	279.8	46.6	139.4	92.8	2.99
Metsulfuron methyl	4.0	22.52	193.0	8.57	274.5	46.4	136.7	90.3	2.94
Carfentrazone	20	22.44	176.0	7.84	249.5	46.5	124.2	77.7	2.67
2,4-D Na (80 WP)	500	22.51	187.1	8.31	263.8	46.5	131.9	85.4	2.84
2,4-D E 38 EC	500	22.60	195.1	8.63	271.7	46.7	136.8	90.1	2.93
Metsulfuron + carfentrazone	4+20	22.52	186.6	8.29	270.6	46.9	133.8	86.9	2.85
2, 4-D Na + carfentrazone	400+20	22.50	183.4	8.15	261.3	46.9	130.0	83.2	2.77
2, 4-D E + carfentrazone	400+20	22.57	191.4	8.48	265.8	47.0	133.9	86.9	2.85
Halauxifen methyl + carfentrazone	10.21+20	22.54	189.1	8.39	253.8	46.9	129.5	82.6	2.76
Weedy check	-	22.41	182.9	8.16	247.1	45.4	125.4	80.0	2.76
Weed-free	-	23.32	201.1	8.62	276.0	52.4	142.4	90.0	2.72

Labourer wages: 350/man-day; market price for wheat: (Grain: ₹1,850 and straw: ₹350/q)

(halauxifen, metsulfuron and 2, 4-DE) were mainly because of higher cost of cultivation and proportionately lower magnitude of increase in wheat yields.

Present study indicates that, post-emergence herbicides halauxifen-methyl-ester @ 12.76 g/ha and metsulfuron methyl @ 4 g/ha were found most effective herbicides in controlling broad-leaf weeds and showed the maximum economics and energy-efficiency parameters apart from wheat productivity compared to weed-free environment in Vertisols of Central India.

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