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Bio-efficacy of ethalfluralin against weeds of potato (*Solanum tuberosum*), its phytotoxicity and effects on productivity and profitability in north-western Himalayan region

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ABSTRACT

Grassy and broadleaf weeds are the major biotic concern in potato (*Solanum tuberosum* L.) crops, affecting the crop yield as well as profitability. The over-dependence on specific herbicides or herbicide with similar modes of action results in the development of herbicide resistance. Herbicide cycling is a strategic approach that alternates the herbicides to mitigate resistance. The present experiment was conducted during the winter (*rabi*) seasons of 2018–19 and 2019–20 at Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh to evaluate the efficacy of a novel herbicide, ethalfluralin, against weeds and its subsequent effect on potato productivity. Bio-efficacy was evaluated with nine weed control treatments comprising five doses of ethalfluralin (540, 630, 720, 810, and 1440 g a.i./ha), sole application of metribuzin 525 g a.i./ha, sole application of oxyfluorfen 200 g a.i./ha, weed-free, and weedy-check, were laid out in a randomized complete block design (RCBD) with three replications. Application of ethalfluralin 720 g a.i./ha as pre-plant incorporation resulted in lower weed density and weed dry weight with weed control efficiency of 62.75% and 70.37% during 2018–19 and 2019–20, respectively. Additionally, ethalfluralin 720 g a.i./ha resulted in significantly higher yield attributes and tuber yield (24.83 t/ha). The higher dose of ethalfluralin (@1440 g a.i./ha) was statistically at par with ethalfluralin (@720 g a.i./ha) but delayed the germination of potato crop and reduced potato tuber yield. From the results, it can be concluded that ethalfluralin at 720 g a.i./ha can be safe and productive for application in potato crops and can be adopted as an alternative to the commercially available herbicides i.e., metribuzin 70% WP and oxyfluorfen 23.5% EC.

Keywords: Ethalfluralin, Phytotoxicity, Potato, Productivity, Weed control efficiency

Weed management is an essential step towards the cultivation of food crops, as it plays a central role in promoting the growth and yield of crop plants. Potato (*Solanum tuberosum* L.), of the family Solanaceae, is the fourth most important staple food crop around the globe, after rice, wheat, and maize. In the year 2021, the global area under potato cultivation was 18.13 million ha with a production of 376.11 Mt, while in India, the potato was cultivated in an area of 2.24 Mha with production of 54.23 Mt (FAOSTAT 2023). Inclusivity of potato crop in the diet is due to its nutritional contribution in terms of carbohydrate (16%), total dietary fiber (13.8%), protein (1.81%), magnesium (22.3 mg), potassium (446 mg), calcium (6 mg), zinc (0.37 mg) and vitamin C (23.3 mg) (USDA 2023). Weeds compete with potato crops for nutrients, space, light, and other resources (Patidar *et al.* 2023). In potato, the occurrence of weeds during their initial growth stages results in the reduction of yield by 10–70% (Sharshar *et al.* 2015 and Gugala *et al.* 2018).

Monitoring the growth of weed during the first 68 days is critical; therefore, it is imperative to use herbicides. The use of pre-plant incorporation widens the window of weed management because of their residual activity and helps delay resistance in weeds. Ethalfluralin (N-ethyl-N-(2-methyl-2-propenyl)- 2,6-dinitro-4- (trifluoromethyl)-benzenamine), a new herbicide belonging to the chemical family dinitroaniline is a yellow crystalline solid with a melting point of 57°C. Ethalfluralin is a selective pre-plant incorporation herbicide used to control grassy and broadleaf weeds. Ethalfluralin was able to reduce the total weed density by 94.4% in a study on potato crops conducted by Taghi *et al.* (2017) in Iran. Ethalfluralin (810 a.i./ha) + halosulfuron (35 a.i./ha) controlled common lambsquarters, barnyard grass, green foxtail, common ragweed, etc. in white bean. Additionally, weed interference decreased by 30–41%

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with ethalfluralin (Soltani *et al.* 2020). However, limited information is available on the efficacy of ethalfluralin in potato hence, it is imperative to study the efficacy and safety of broad-spectrum weed control through ethalfluralin in potato crops.

MATERIALS AND METHODS

The present experiment was conducted during the winter (*rabi*) seasons of 2018–19 and 2019–20 at Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur (32°6' N latitude, 76°3' E longitude, and elevation of 1290.8 m amsl), Himachal Pradesh. Agroclimatically, the experimental site falls under the sub-temperate and sub-humid zone of Himachal Pradesh, characterized by mild summers, heavy rainfall during monsoons, and severe winters. Soil at the site was silty clay loam in texture and acidic in reaction (*p*H 5.6). It was low in organic carbon (0.72%), low in available nitrogen (242 kg/ha), medium in available phosphorus (18.8 kg/ha), and available potassium (182.1 kg/ha).

The experiment was laid out in randomized complete block design (RCBD) having three replications and nine weed control treatments consisting of 5-doses of ethalfluralin 36% EC (at 540, 630, 720, 810 and 1440 g a.i./ha) (pre-plant incorporation), sole application of metribuzin 70% WP at 525 g/ha (pre-emergence), sole application of oxyfluorfen 23.5% EC at 200 g a.i./ha (pre-emergence), weed-free (hand weeding) and weedy-check. Sowing of potato tuber variety Kufri Jyoti was done manually with a seed rate of 28 q/ha. The observations on the weed in potato crops under different herbicidal treatments were made at 60 and 120 days after application (DAA) by using a quadrant of 0.5 m × 0.5 m placed at two sites in each experimental plot. The samples were oven-dried at 70°C till constant weight was obtained. In order to study the persistence of any phytotoxic effect of ethalfluralin doses maize crop was sown during the subsequent season. The data pertaining to weed count and weed dry weight were subjected to square root transformation ($\sqrt{x} + 1$). Weed Control Efficiency (WCE) was calculated using the formulation mentioned by Lal *et al.* (2017).

$$WCE = \frac{DW_C - DW_T}{DW_C} \times 100$$

Where DW_C and DW_T, Dry weight(s) of weeds (g) in control and treated plots, respectively.

Data on weed count, weed dry weight, yield attributes and yield were subjected to statistical analysis by the techniques as outlined by Gomez and Gomez (1984). Wherever the variance ratio was found significant at a 5% level of significance for the treatment effects, the critical difference values were computed for that level. Additionally, statistical analysis of data pertaining to gross returns, net returns and benefit-cost ratio were performed using R-Software (RStudio 2023.06.2+561 "Mountain Hydrangea") using the package "agricolae," whereas data visualization was achieved using the "ggplot2" package (R Core Team 2023).

RESULTS AND DISCUSSION

Species-wise weed count: The pooled data pertaining to species-wise weed population at 60 and 120 DAA has been presented in Table 1. Hand-weeding treatment was able to maintain weed-free conditions during the entire cropping season, minimizing the dry weight accumulated by the weeds (Table 2) as a result emerged as the best treatment in controlling the weed population in potato. Besides, the perusal of data revealed that the weed count increased as days to planting increases. This might be attributed to the herbicide losing its efficacy as the crop approaches maturity. *Coronopus didymus* was effectively controlled by oxyfluorfen 23.5% EC at 200 g a.i./ha and metribuzin 70% WP at 525 g a.i./ha at 60 and 120 DAA during both years of experimentation. Ethalfluralin 36% EC at 1440 g a.i./ha was found to be statistically at par with oxyfluorfen and metribuzin in controlling *Coronopus didymus* at 60 DAA but it failed to control weed at 120 DAA which might be attributed to the herbicide losing its effectiveness after a period of time. Kumar *et al.* (2012) reported the superiority of metribuzin and hand-weeding in controlling *Coronopus didymus.* Ethalfluralin 36% EC at 720 and 810 g a.i./ha, were the second-best treatment in controlling the weed. *Phalaris minor* was effectively controlled by all herbicide treatments during both years of experimentation except for ethalfluralin 36% EC at 630 and 540 g a.i./ha, and weedy check plots. The low dosage of the herbicides might have influenced the weed population resulting in higher population of *Phalaris minor* than other treatments. Metribuzin at 525 g a.i./ha was unable to effectively control *Phalaris minor* at 120 DAA, which could be related to the weed's maturity decreasing the herbicide treatment's potency.

In case of *Plantago* spp., *Avena ludoviciana, Lolium temulentum, Vicia sativa* and *Trifolium repens* all herbicide treatments were found to be statistically at par with the hand-weeding treatment except for Ethalfluralin 36% EC at 540 and 630 g a.i./ha at 60 and 120 DAA. This may be explained by the fact that the weed population was at its maturity and the low herbicide dosage led to inadequate control of the weed flora at later stages when compared to other treatments at 120 DAA. The less prominent weed species, including *Anagallis arvensis, Stellaria media, Lathyrus aphaca, Galinsoga parviflora, Veronica* spp., *Medicago denticulata, Cannabis sativa, Poa annua,* and *Euphorbia hirta*, were grouped as "other weeds." The herbicide treatments in comparison to weedy check were able to significantly control the weed species. Among the herbicides, oxyfluorfen 23.5% EC at 200 g a.i./ha and ethalfluralin 36% EC at 1440 and 720 g a.i./ha were found to be statistically at par with hand-weeding treatments. The effectiveness of ethalfluralin in weed control depends on its capacity to interfere with cellular processes in weed seed germination due to the herbicide residual activity. The efficacy of ethalfluralin as pre-emergence herbicide had been well established in the study by Tonks *et al.* (2000). It was able to control 95% green foxtail while the efficiency in controlling the weed population of *Chenopodium*

Table 1 Effect of treatments on the number of weeds in potato at 60 and 120 DAA (pooled data of two years)

Treatment	*Coronopus didymus*		*Phalaris minor*		*Plantago* spp.		*Avena ludoviciana*		*Lolium temulentum*		*Vicia sativa*		*Trifolium repens*		Others	
	60 DAA	120 DAA	60 DAA	120 DAA	60 DAA	120 DAA	60 DAA	120 DAA	60 DAA	120 DAA	60 DAA	120 DAA	60 DAA	120 DAA	60 DAA	120 DAA
T_1, Ethalfluralin 36% EC @540 g a.i./ha (PPI)	2.9 (8.0)	6.0 (34.7)	2.2 (4.0)	3.0 (8.0)	1.0 (0.0)	2.5 (5.3)	2.1 (4.0)	3.0 (8.0)	2.1 (4.0)	2.2 (4.0)	1.8 (2.7)	2.5 (5.3)	1.8 (2.7)	2.7 (6.7)	3.9 (14.7)	3.6 (12.0)
T_2, Ethalfluralin 36% EC @630 g a.i./ha (PPI)	2.7 (6.7)	5.8 (33.3)	1.8 (2.7)	2.7 (6.7)	1.0 (0.0)	1.8 (2.7)	1.8 (2.7)	2.5 (5.3)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	2.1 (4.0)	1.4 (1.3)	2.1 (4.0)	3.4 (10.7)	3.4 (10.7)
T_3, Ethalfluralin 36% EC @720 g a.i./ha (PPI)	2.1 (4.0)	4.9 (22.7)	1.0 (0.0)	2.1 (4.0)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	1.8 (2.7)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	1.8 (2.7)	2.1 (4.0)	2.1 (4.0)
T_4 Ethalfluralin 36% EC @810 g a.i./ha (PPI)	2.1 (4.0)	4.7 (21.3)	1.0 (0.0)	1.7 (2.7)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.8 (2.7)	1.4 (1.3)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.8 (2.7)	2.2 (4.0)	2.1 (4.0)
T_5, Metribuzin 70% WP @525 g a.i./ha (Pre)	1.4 (1.3)	2.2 (4.0)	1.4 (1.3)	2.5 (5.3)	1.0 (0.0)	1.0 (0.0)	1.8 (0.0)	2.2 (4.0)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	2.2 (4.0)	1.0 (0.0)	1.0 (0.0)	2.2 (4.0)	2.5 (5.3)
T_6, Oxyfluorfen 23.5% EC @200 g a.i./ha (Pre	1.4 (1.3)	1.8 (2.7)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	1.0 (0.0)	2.1 (4.0)	3.0 (8.0)	2.1 (4.0)	1.8 (2.7)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.8 (2.7)	1.8 (2.7)
T_7, Ethalfluralin 36% EC @1440 g a.i./ha (PPI)	1.8 (2.7)	4.4 (18.7)	1.0 (0.0)	1.8 (2.7)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.7 (2.7)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.4 (1.3)	1.0 (0.0)	1.7 (2.7)	2.1 (4.0)	1.8 (2.7)
T_8, Hand weeding (Weed-free)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
T_9, Weedy check	2.7 (6.7)	6.2 (37.3)	2.5 (5.3)	4.4 (18.7)	1.8 (2.7)	1.0 (0.0)	2.5 (5.3)	3.2 (9.3)	2.5 (5.3)	2.7 (6.7)	1.8 (2.7)	3.0 (8.0)	1.8 (2.7)	3.0 (8.0)	4.1 (16.0)	3.8 (13.3)
SEM±	0.3	0.4	0.2	0.4	0.1	0.2	0.3	0.4	0.3	0.2	0.2	0.3	0.1	0.3	0.4	0.4
LSD (P=0.05)	1.0	1.3	0.6	1.2	0.4	0.7	0.8	1.2	0.8	0.7	0.6	0.8	0.4	1.0	1.1	1.1

*Values given in parenthesis are the means of original values. PPI, Pre-plant incorporation; DAA, Days after application.

giganteum, *Amaranthus retroflexus*, *Solanum sarrachoides* and volunteer oat varied from 54–82%.

Total weed count, weed dry weight, and weed control efficiency: On the basis of data on total weed count at 60 DAA (Table 2), ethalfluralin 36% EC at 720, 810 and 1440 g a.i./ha were statistically at par with the commercial herbicides metribuzin 70% WP at 525 g a.i./ha and oxyfluorfen 23.5% EC at 200 g a.i./ha in controlling the weed population during both years. Although hand-weeding treatment was best in controlling the weeds but due to the higher efficacy of the herbicide treatments they were found to be at par with each other. On the other hand, at 120 DAA during the initial year, all herbicide treatments were statistically at par with each other (Table 2) whereas during the second year, metribuzin and oxyfluorfen were at par with hand-weeding treatment, whereas ethalfluralin 36% EC (at 720, 810, and 1440 g a.i./ha) was the second best among the herbicide treatment. The efficacy of ethalfluralin 36% EC at 720, 810, and 1440 g a.i./ha was effective in controlling the weed dry weight at 60 DAA during both years and found to be at par with commercial recommended herbicides, i.e. metribuzin 70% WP and oxyfluorfen 23.5% EC (Table 2). A similar trend was observed for total weed dry weight at 120 DAA. The reason for decrease in the total dry weight can be attributed to the efficacy of herbicide treatments in controlling the plant population as presented in the Table 1. The activity of oxyfluorfen 23.5% EC at 200 g a.i./ha was highest during both years evident by the weed control efficiencies (91.08% and 92.56%, respectively) in controlling the dry weight presented in Table 2, which was followed by metribuzin 70% WP at 525 g a.i./ha during the initial year whereas during the second year it was followed by the pre-plant incorporation herbicide ethalfluralin 36% EC at 1440 g a.i./ha. During both years, ethalfluralin 36% EC at 720 (62.75% and 70.37%, respectively) and 810 g a.i./ha (62.43% and 67.42%, respectively) proved significantly effective in controlling weed dry weight after oxyfluorfen and metribuzin. The lower weed efficiencies of pre-plant incorporated herbicides might be due to the poor control of *Coronopus didymus* as evident from the weed count data presented in Table 1 adding to the total dry weight of the weeds. The results corroborate with the findings of Thakral *et al.* (1988), Kumar *et al.* (2007) and Kumar *et al.* (2008).

Yield attributes and tuber yield: A cursory glance of a two-year pooled data on the yield attributes of potato as influenced by the treatments (Table 3) revealed that number of plants per meter row were not significantly affected. Number of tubers/plant and weight of tubers/plant were significantly affected. Significantly higher tubers (6.00) and weight of tubers (231.55 g) per plant were achieved when

Table 2 Effect of different treatments on total weed count, total weed dry weight and weed control efficiency in potato at 60 and 120 DAA during 2018–2019 and 2019–2020

Treatment	Dose (a.i./ha)	Total weed count (No./m^2)				Total weed dry weight (g/m^2)				Weed control efficiency (%)	
		60 DAA		120 DAA		60 DAA		120 DAA		120 DAS	
		2018–19*	2019–20*	2018-19*	2019–20*	2018–19*	2019–20*	2018–19*	2019–20*	2018–19	2019–20
T_1, Ethalfluralin 36% EC @540 g a.i./ha (PPI)	540	6.0 (34.7)	6.3 (38.7)	8.9 (78.7)	9.1 (82.7)	4.2 (16.9)	4.0 (15.0)	12.5 (156.3)	12.9 (166.3)	27.77	43.56
T_2, Ethalfluralin 36% EC @630 g a.i./ha (PPI)	630	4.9 (22.7)	4.5 (20.0)	8.0 (62.7)	7.8 (61.3)	3.6 (12.5)	2.7 (6.4)	11.1 (130.3)	10.6 (113.3)	39.78	61.55
T_3, Ethalfluralin 36% EC @720 g a.i./ha (PPI)	720	2.9 (8.0)	3.7 (13.2)	5.8 (33.3)	6.5 (42.7)	2.6 (5.6)	1.8 (2.3)	9.0 (80.6)	9.3 (87.3)	62.75	70.37
T_4 Ethalfluralin 36% EC @810 g a.i./ha (PPI)	810	2.9 (8.0)	3.5 (11.9)	5.8 (33.3)	6.2 (38.0)	2.4 (5.5)	1.9 (2.7)	9.0 (81.3)	9.8 (96.0)	62.43	67.42
T_5, Metribuzin 70% WP @525 g a.i./ha (Pre)	525	2.7 (6.7)	4.1 (16.0)	5.0 (25.3)	6.7 (45.3)	1.9 (2.8)	2.2 (4.2)	6.0 (35.3)	7.9 (63.3)	83.68	78.52
T_6, Oxyfluorfen 23.5% EC @200 g a.i./ha (Pre)	200	3.1 (9.3)	3.9 (14.6)	4.3 (17.3)	4.8 (23.3)	2.1 (3.7)	2.0 (3.3)	4.5 (19.3)	4.6 (21.9)	91.08	92.56
T_7, Ethalfluralin 36% EC @1440 g a.i./ha (PPI)	1440	2.5 (5.3)	2.4 (5.3)	5.5 (30.7)	4.7 (22.7)	2.2 (4.4)	2.1 (3.8)	8.8 (76.5)	6.3 (40.1)	64.64	86.39
T_8, Hand weeding (Weed-free)	-	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	100	100
T_9, Weedy check	-	6.9 (46.7)	8.0 (63,9)	10.5 (109.3)	11.9 (141.3)	5.6 (30.3)	6.5 (41.4)	14.7 (216.4)	17.1 (294.7)	-	-
SEM ±		0.3	0.2	0.7	0.6	0.5	0.5	1.9	1.8	-	-
LSD (P=0.05)		0.9	0.7	2.2	1.9	1.6	1.5	5.8	5.5	-	-

*Values given in parenthesis are the means of original values. PPI, Pre-plant incorporation; DAA, Days after application, DAS, Days after sowing.

Table 3 Effect of different treatments on yield attributes (pooled data), potato tuber yield and maize green cob yield during 2018–19 and 2019–20

Treatment	Yield attributes (Pooled data of 2 years)			Potato tuber yield (t/ha)		Green cob yield (t/ha)	
	Number of plants/m^2	Number of tubers/plant	Weight of tuber/plant (g)	2018–19	2019–20	2018–19	2019–20
T_1, Ethalfluralin 36% EC @540 g a.i./ha (PPI)	4.60	5.57	159.35	17.73	18.04	24.08	25.02
T_2, Ethalfluralin 36% EC @630 g a.i./ha (PPI)	4.78	5.60	175.18	19.65	19.26	24.21	25.44
T_3, Ethalfluralin 36% EC @720 g a.i./ha (PPI)	4.91	5.82	224.12	25.42	24.24	24.22	25.68
T_4 Ethalfluralin 36% EC @810 g a.i./ha (PPI)	4.88	5.83	216.98	24.68	24.09	25.06	26.22
T_5, Metribuzin 70% WP @525 g a.i./ha (Pre)	4.90	5.76	221.40	24.70	23.88	24.18	25.28
T_6, Oxyfluorfen 23.5% EC @200 g a.i./ha (Pre)	4.80	5.88	227.82	25.42	23.94	24.66	25.72
T_7, Ethalfluralin 36% EC @1440 g a.i./ha (PPI)	4.41	5.65	193.18	21.66	20.55	25.01	25.88
T_8, Hand weeding (Weed-free)	4.90	6.00	231.55	26.06	25.08	24.82	25.64
T_9, Weedy check	4.92	5.18	129.11	14.31	14.92	23.82	24.88
SEM±	0.12	0.08	8.40	1.02	1.13	-	-
LSD (*P*=0.05)	NS	0.25	25.16	3.07	3.39	NS	NS

*Values given in parenthesis are the means of original values. PPI, Pre-plant incorporation; DAA, Days after application.

hand-weeding was performed which can be attributed to no competition for nutrients, space and water due to weed free conditions during the entire period of crop season. Oxyfluorfen 23.5% EC at 200 g a.i. /ha was found to be statistically at par with hand weeding treatment in terms of number of tubers (5.88) and tuber weight per plant (227.82 g). Ethalfluralin 36% EC at 720 g a.i./ha and metribuzin were also found to be at par with hand-weeding treatments with number of tubers 5.82 and 5.76, respectively and tuber weight 224.12 g and 221.40 g, respectively. The lower number of tubers and tuber weight/plant under the influence of ethalfluralin 36% EC at 1440 g a.i./ha might be due to slight toxicity from the higher dose of herbicide treatment which resulted in the delay of germination of potato plant.

The highest potato tuber yield (26.06 and 25.08 t/ha, respectively) was harvested from hand-weeding treatment. This might be explained by the periodical removal of weeds for the duration of the crop. The crop was able to produce more since there was no competition for resources like nutrients, water, or space. Among the herbicide treatments, ethalfluralin 36% EC at 720 g a.i./ha (25.42 and 24.24 t/ha, respectively) was at par with the hand weeding treatment, oxyfluorfen, and metribuzin treatments during both years (Table 3). Ethalfluralin 36% EC at 810 g a.i./ha, was also at par with the above mentioned herbicide treatments. As far as higher dosage of ethalfluralin 36% EC @1440 g a.i./ha is concerned, there was decline in the tuber yield (21.66 and 20.55 t/ha, respectively) which might be attributed to the slight toxicity. The moderate persistence combined with high dose of herbicide although was able to effectively control weeds (64.64 and 86.39%, respectively) (Table 2) but also resulted in delayed germination of the potato crop because of it is known to have a significant effect in the seedling growth. The high dose might have affected the selectivity of herbicide hence the decline in tuber yield during both years. Carvalho *et al.* (2009) suggested that selectivity is due to physiological response of the plants to toxin but in certain cases, though the plants are protected by the metabolism process but in other cases the toxin might reach the target site causing damage. The plants spend certain amount of energy, which cannot be considered as a part of response to protect itself from the herbicide, to recover which might compromise crop yield. Gwatidzo *et al.* (2023) also suggested that tolerant crops are stripped off their physical or physiological selectivity due to higher dosage of herbicides. The maize green cob yield was not significantly affected by weed control treatments (Table 3).

Economics and phytotoxicity studies: In economic terms, ethalfluralin 36% EC at 720 g a.i./ha gave the highest net returns (₹2,17,306/ha and ₹1,99,516/ha) and net benefit-cost (1.32 and 1.22) during both years (Fig. 1a, 1b and 2). Besides higher yield, the low cost of ethalfluralin herbicides resulted in higher net benefit-cost as compared to other herbicide treatments or hand-weeding treatment. The low net benefit-cost of 1.17 and 1.09 under hand-weeding treatment might be due to the labour-intensive approach of

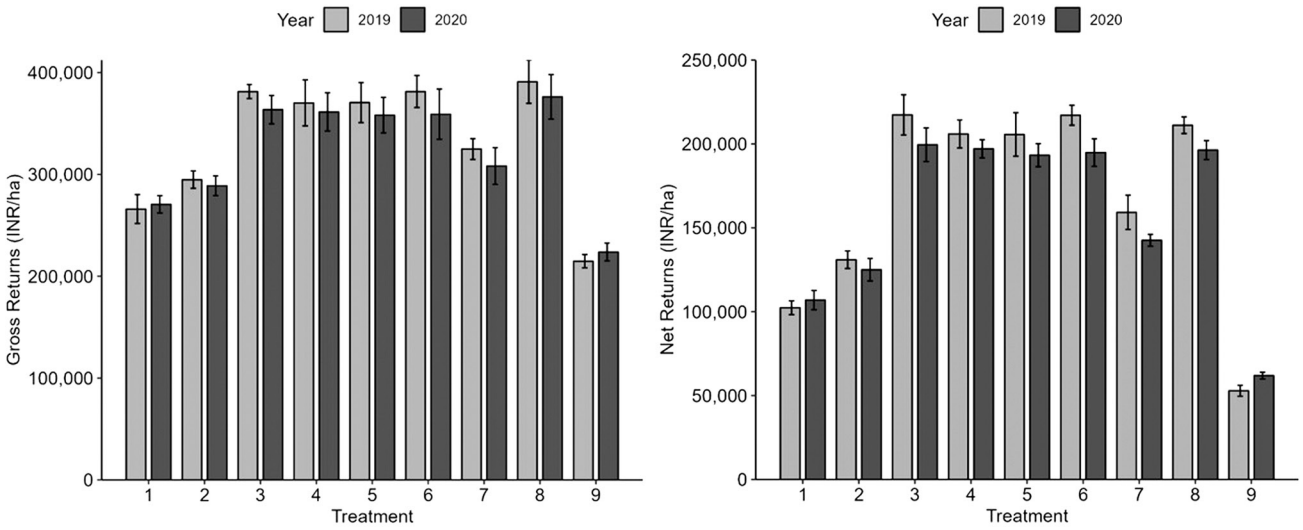

Fig. 1 (A) Effect of different treatments on the (A) Gross returns; (B) Net returns in potato during 2018–19 and 2019–20. Treatment details are given under Materials and Methods.

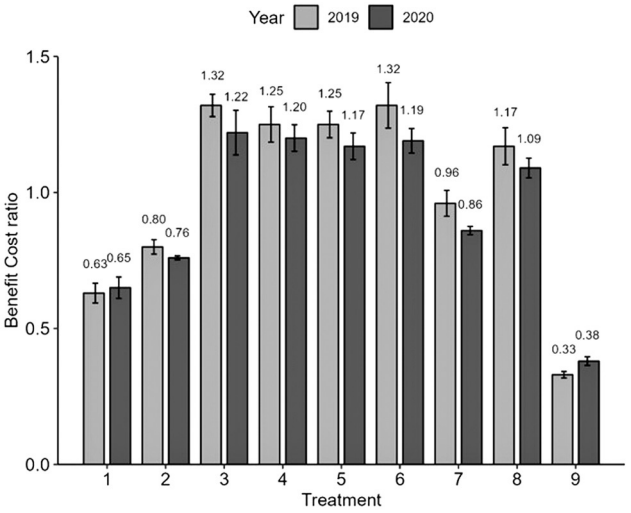

Fig. 2 Effect of different treatments on the benefit-cost ratio in potato during 2018–19 and 2019–20.
Treatment details are given under Materials and Methods.

the treatment to keep the plot weed free during the entire crop duration. Lowest benefit-cost of 0.33 and 0.38 were obtained under weedy check plots. Phytotoxicity observations were recorded at 1, 3, 5 and 7 days after emergence of potato. Observations for the specific parameters like chlorosis, necrosis, wilting, scorching, hyponasty and epinasty were recorded using phytotoxicity rating scale by Rao (1986). In order to study the phytotoxicity of ethalfluralin, maize crop was sown after harvesting potato tuber. Visible phytotoxicity in potato crop was not observed or in the succeeding maize crop at germination, 60 days after sowing or at harvest.

The application of pre-plant incorporation herbicide ethalfluralin 36% EC at 720, 810, and 1440 g a.i./ha effectively controlled majority of the grassy weeds in potato crop. However, the herbicides doses exhibited limited efficacy in controlling some of the broadleaf weeds such as *Coronopus didymus*. Among the varied doses, ethalfluralin 36% EC at 720 g a.i./ha gave higher tuber yield and economic return. Although there was no visible toxicity with the herbicide treatments, ethalfluralin 1440 g a.i./ha delayed the germination of potato crops by a few days as compared to other ethalfluralin treatments. Ethalfluralin 36% EC at 720 g a.i./ha offered performance comparable to commercial herbicides such as metribuzin 70% WP at 525 g a.i./ha and oxyfluorfen 23.5% EC at 200 g a.i./ha without any phytotoxic effect. Therefore, it can be recommended as an effective, economical, and safe alternative for weed management in potato or subsequent crops in rotation.

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