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Effects of various weed management methods on growth and yield of potato (*Solanum tuberosum* L.)

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Abstract
A field experiment was carried out at Research block of S.G.R.R University, Dehradun, Uttarakhand during *Rabi* season of 2019-2020 to record the response of various weed management methods on growth and yield of Potato (*Solanum tuberosum* L.) The experiment was carried out in Randomized Block Design (RBD). Eight treatments were adopted for the experiment with three replications each. Kufri Jyoti is an early maturing variety in hills. The major weed species observed during the course of the experiment were *Cyperus rotundus* (sedge), *Eleusine indica* and *Digitaria sanguinalis* among grassy weeds and Medicago denticulata, *Chenopodium album* and *Amaranthus virdis* among broad leaf weeds. The results stated that treatment T_2 (Pendimethalin 350 g ha^{-1} as pre-emergent application) was most effective in controlling weeds and recorded with highest weed control efficiency (47.84 %), highest number of tubers (96.00) and maximum yield (61.5 Kg). Besides, minimum dry biomass of weed (29.59 g m^{-2}), lowest weed density per meter square (61.25 m^{-2}) at 60 Days after sowing (DAS) and at harvesting stage of crop (54.97 m^{-2}) were recorded under Treatment T_2 (Pendimethalin 350 g ha^{-1} as pre-emergent application). Whereas, treatment T_1 i.e. weedy check (control), was least effective in controlling weeds and also recorded maximum weed density m^{-2} at 60 DAS (110.31 m^{-2}) and at harvesting stage (97.31 m^{-2}). T_1 also recorded maximum weed dry biomass (56.73 g m^{-2}) and showed lowest yield (30.90 kg).

Keywords: weed management, yield of potato, *Rabi* season

Introduction
Potato (*Solanum tuberosum* L.) a tuber crop belongs to family, Solanaceae acts as a main source of starch supply all over the world. The center of origin of Potato is in South America in the central Andean region. Although potato is a temperate region crop but gives best results in the temperature range of 18-22 ºC, it can be grown in subtropical and tropical regions (Hijmans and Spooner, 2001) [3]. Weeds are harmful in many ways like compete with crops for water, nutrients and light and ultimately leads to reduction in crop yield. Due to hardy and vigorous in growth habit, weeds grow faster than crops and consume large amount of water and nutrients, thus causes substantial yield losses. Weeds prevalent in potato crop vary from region to region**.** The dominant weeds of potato crop in Indo-gangetic plains are *Cynodon dactylon* L.(Pers.), *Cyperus rotundus* L., *Trianthema monogyna* L., *Chenopodium album* L. *Poa annua* L. *Anagallis arvensis* L., *Meliotus* spp., *Sonchus oleraceus* L. and *Vicia sativa* L. Major weeds of hills are *Amaranthus viridis* L., *Chenopodium* spp., *Oxalis* spp., *Digitaria sanguinalis* (L.) Scop. *Setaria glauca* (L). Beauv, *Spergula arvensis* L. and *Meliotus* spp. (Lal 1993) [4]. Potato is planted in early spring in temperate regions and late winter in tropical regions. The growing period of Potato is around Four months. Weeds pose a major threat to the proper growth and development of Potato. They compete for the resources with Potato crop and are hard to suppress if not taken care of early. Therefore, weed management plan is a critical aspect of Potato cultivation. The most critical period for crop- weed competition is 25-35 Days after planting (Jaiswal and Grewal, 1991) [1].

Weeds are unwanted plants which compete with crops for nutrients, space, moisture and light. Thus, weeds are considered as a major threat to crop yield and their survival. Weeds are well adapted to adverse conditions unlike the crops and their growth in a field leaves the soil devoid of nutrients. Potato is particularly a vulnerable crop to weed competition during the period from emergence to the time it develops full crop canopy. Weeds along with depleting resources also hinder the crop growth by releasing allochemicals and by harbouring harmful insects and pathogens. Biswajit *et al*. (2012) showed that the predominant weed flora in experimental field of Potato was *Cyperus rotundus, Chenopodium album, Anagallis arvensis* and *Fumaria parviflora.* Raj Kumar (2015) at Chaudhary Charan Singh Agriculture University reported that predominant weed species infesting Potato crop in direct weeds were *Fumaria parviflora, Chenopodium album, Convolvulus arvensis, Melilotus indica* while monocot weeds were *Cyperus rotundus, Asphodelus tenuifolius* and *Circium arvensis.*

The occurrence and intensity of weeds vary under various agro climatic regions, cropping systems and management conditions. The competitive ability of the potato plant varies considerably among the different varieties. The main objective of weed management is to keep the intensity of these undesirable plants without hampering the farm profits and tuber yields. Thus, the there is need to find out the most suitable method of weed control would depend upon severity of specific weeds, stage of weed growth under Dehradun conditions. Therefore, an experiment was laid out to find out the the most feasible practices towards weed management for the potato crop cultivation either cultural, mechanical or chemical.

Materials and Methods

The experiment was conducted during Rabi season of 2019-2020 at S.G.R.R. University, Dehradun, Uttarakhand between $29^0$58' and $31^0$2'30 North latitude and $77^0$34'45" and $78^0$18'30" east longitudes at 450 meters above the mean sea level (MSL). Kufri Jyoti is an early maturing variety in hills with a yield potential of 20 tons ha^{-1}. It is moderately resistant to late and early blight diseases. Tubers are white, large, oval, and smooth with White flesh was sown in plots of size 4 x 3 m^2. The seeds were treated with Maxim 4FS. Sowing of seeds were done on 18th October 2019. The spacing maintained between the rows was 60 cm and 20 cm between plants. The texture of the soil on which crop was cultivated was sandy loam with a pH of 6.8 and 0.01 dSm^{-1}. The recommended dose of fertilizers were applied to the crop. The claimate was under humid subtropical category, temperature varies with altitude. The temperature ranged between 12 to 35 ^{0}C during the cropping season. There were eight treatments with three replications in a Randomized Block Design (RBD) was adopted for weed management practices. Various treatments *i.e.* T_1 - Weedy check (Control plot), T_2 - Pendimethalin 350 g ha^{-1} at pre-emergence stage, T_3 - Metribuzin 350 g ha^{-1}, T_4 - Clodinafop 60 g ha^{-1}, T_5 - Clodinafop+ Metribuzin 195 g ha^{-1}, T_6 - Clodinafop+Metribuzin 260 g ha^{-1}, T_7 - Paddy Straw Mulch (PSM) 6 t ha^{-1} and T_8 - Hand Weeding; respectively were adopted at post emergence stage as shown in Table 1. Pre-emergence herbicide was sprayed with a knapsack sprayer using 30 litre of water for 300 m2 area (whole experimental plot). Paddy straw mulch was spread uniformly over the plots as per treatments. Post-emergence application of herbicides was done using 30 litre water spray volume at 15 DAS. Before sowing the Potato, first irrigation was applied to make sure good germination. Two more irrigation were given during the time of whole experiment.

Table 1: Various weed management treatments and their date of application

	Treatments	Date of application
T_1	Weedy check	NA
T_2	Pendimethalin 350 g ha^{-1} as PE	19.11.2019
T_3	Metribuzin 350 g ha^{-1} as POEM	2.11.2019
T_4	Clodinafop 60 g ha^{-1} as POEM	2.11.2019
T_5	Clodinafop + Metribuzin 195 gha^{-1} as POEM	2.11.2019
T_6	Clodinafop + Metribuzin 260 g ha^{-1} as POEM	2.11.2019
T_7	Paddy straw mulch 6 t ha^{-1}	2.11.2019
T_8	Hand weeding	17.11.2019 & 17.12.2019

***Note:** PE = Pre-emergent application, POEM = Post-emergent application

The growth parameters recorded during the experiment were plant height, number of leaves per m^2, number of tubers and crop yield. For recording plant height, ten plants were randomly selected and tagged from each plot. Their height was measured from ground level to tip. This parameter was recorded at 60 DAS and at harvest. A quadrate of 1 m x 1 m was used to select plants for calculating number of leaves per m^2, weed dry biomass and weed control efficiency (WCE). Weeds under the area of the quadrate were cut out and oven dried at 65 ^{o}C temperature and then weighed to calculate dry biomass and Weed control efficiency. Potato plants under the quadrant area were selected to count number of leaves. Five plants were randomly selected form each plot to calculate number of tubers during harvesting. The data was subjected to analysis of variance (ANOVA).

Results and Discussion

Weed biomass (In gm^{-2})

Weed biomass was calculated by categorizing weeds in sedges, grasses and broad leaf weeds and not species wise. Weed biomass was calculated at harvesting stage only. Lowest sedge biomass was recorded in treatment T_2 i.e., Pendimethalin 350 g ha^{-1} as pre-emergent application (6.63 g m^{-2}) followed by treatment T_3 i.e., Metribuzin 350 g ha^{-1} as post-emergent application (8.33 g ha^{-1}). Highest sedge biomass was observed in treatment T_1 weedy check (15.83 g m^{-2}) as weed population was maximum in that treatment. Treatment T_1 i.e. weedy check showed highest grassy weed biomass (18.60 g m^{-2}). Treatment T_3 i.e. Metribuzin 350 g ha^{-1} as pre-emergent application showed lowest grassy weed biomass (9.90 g m^{-2}) followed by treatment T_2 i.e. Pendimethalin 350 g ha^{-1} as post-emergent application (11.00 g m^{-2}). Highest broad leaf weed biomass was recorded from treatment T_1 i.e. weedy check (22.30 g m^{-2}). Lowest broad leaf weed biomass was recorded from treatment T_1 i.e. Pendimethalin 350 g ha^{-1} as pre-emergent application (11.96 g m^{-2}) followed by treatment T_3 Metribuzin 350 g ha^{-1} as post-emergent application (12.70 g m^{-2}). Similarly, Patel *et al.* (1995) reported that all three hand weeding treatments (at 30, 45 and 65 DAP) significantly reduced the dry weight of weeds in Potato over unweeded control in all growth stages, hence one hand weeding at 30 DAP was found as good as that of weed free treatment.

Table 2: Weed dry biomass (g m^{-2}) at harvest as influenced by various treatments

	Treatments	Sedges	Grassy weeds	Broad leaf weeds
T_1	Weedy check	15.83	18.60	22.30
T_2	Pendimethalin 350 g ha^{-1} as PE	6.63	11.00	11.96
T_3	Metribuzin 350 g ha^{-1} as POEM	8.33	9.90	12.70
T_4	Clodinafop 60 g ha^{-1} as POEM	12.6	14.66	16.90
T_5	Clodinafop + Metribuzin 195 g ha^{-1} as POEM	10.03	12.56	14.60
T_6	Clodinafop + Metribuzin 260 g ha^{-1} as POEM	12.2	15.86	17.66
T_7	Paddy straw mulch 6 t ha^{-1}	8.6	12.16	14.26
T_8	Hand weeding	14.5	16.46	19.23
	SEm±	0.972	0.85	1.073
	CD (*P*=0.05)	1.71	1.496	1.88

Note: PE= pre-emergence, POEM= post-emergence, weed control efficiency (WCE)

Treatment T_2 i.e., Pendimethalin 350 g ha^{-1} as pre-emergence application showed maximum WCE (58.33 %) for Sedges followed by treatment T_3 i.e., Metribuzin 350 g ha^{-1} as post-emergent application (47.91 %). Treatment T_8 i.e. Hand weeding showed the least WCE (8.33 %). For grassy weeds, treatment T_3 i.e., Metribuzin 350 g ha^{-1} as post-emergent application showed highest WCE (46.42 %) followed by

treatment T_2 i.e. Pendimethalin 350 g ha^{-1} as post-emergent application (41.07 %). Least WCE for grassy weeds was recorded in treatment T_8 i.e., Hand weeding (10.71 %). Treatment T_2 i.e., Pendimethalin 350 g ha^{-1} as pre- emergent application showed maximum WCE for broad leaf weeds (46.26 %) followed by treatment T_3 i.e., Metribuzin 350 g ha^{-1} as post-emergent application (43.28 %). Minimum WCE for broad leaf weeds was observed in treatment T_8 i.e., hand weeding (13.43 %). Similarly, Singh (1982) reported that hand weeding in Potato at 25 DAP produced significantly higher tuber yield than weed removed at 40, 55 and 70 DAP. Gogoi *et al*. (1991) reported that the weed control through hand weeding in Potato showed 31% weed control efficiency which was found on par with weed control by Fluchloralin (2 Kg per Ha).

Table 3: Weed control efficiency (%) of various treatments

Treatments		Weed control efficiency (WCE) In %		
		Sedges	**Grassy weeds**	**Broad leaf weeds**
T_1	Weedy check	0.00	0.00	0.00
T_2	Pendimethalin 350 g ha^{-1} as PE	58.33	41.07	46.26
T_3	Metribuzin 350 g ha^{-1} as POEM	47.91	46.42	43.28
T_4	Clodinafop 60 g ha^{-1} as POEM	20.80	21.42	23.88
T_5	Clodinafop+ Metribuzin 195 g ha^{-1} as POEM	35.41	32.14	34.32
T_6	Clodinafop+ Metribuzin 260 g ha^{-1} as POEM	22.91	16.07	17.91
T_7	Paddy straw mulch 6 t ha^{-1}	45.83	33.92	35.82
T_8	Hand weeding	8.33	10.71	13.43

Note: PE = pre-emergent, POEM = post-emergent

Plant height (cm)

Analysis of variance showed significant difference in plant height of Potato plant as shown in Table 2. Treatment T_4 *i.e.* Clodinafop 60 g ha^{-1} recorded maximum height (29.83 cm) followed by Clodinafop+ Metribuzin 260 g ha^{-1} as post-emergent application POEM at 60 DAS (27.70 cm). However, treatment T_1 *i.e.* weedy check recorded minimum plant height for Potato at 60 DAS (25.36 cm) and at harvest (32.16 cm). Althouhg at harvest stage least plant height was observed in the treatment T_1 i.e. weedy check (32.00 cm). Maximum plant height was observed in treatment T4 *i.e.* Clodinafop 60 g ha^{-1} as post-emergent application (38.33 cm) followed by treatment T_3 i.e., Metribuzin 350 g ha^{-1} as post-emergent application and treatment T_5 i.e. Clodinafop+ Metribuzin 195 g ha^{-1} as post-emergent application (37.00 cm). Similarly, Kumar Raj (2015) reported that significantly maximum plant height was recorded with Atrazine @ 250 g ha^{-1} as pre-emergence closely followed by Pendimethalin @ 1000 g ha^{-1} as pre-emergence and Metribuzin @ 350 g ha^{-1} as pre-emergence.

Table 4: Plant height (in cm) of potato plants as influenced by various treatments

	Treatments	At 60 DAP (in cm)	At harvest (in cm)
T_1	Weedy check	25.36	32.16
T_2	Pendimethalin 350 g ha^{-1} as PE	27.30	36.66
T_3	Metribuzin 350 g ha^{-1} as POEM	25.96	37.00
T_4	Clodinafop 60 g ha^{-1} as POEM	29.83	38.33
T_5	Clodinafop+ Metribuzin 195 g ha^{-1} as POEM	27.66	36.80
T_6	Clodinafop+ Metribuzin 260 g ha^{-1} as POEM	27.70	36.80
T_7	Paddy straw mulch 6 t ha^{-1}	26.66	36.43
T_8	Hand weeding	27.00	35.03
	SEm±	1.1	1.21
	CD (*P*=0.05)	1.77	2.13

Note: PE= pre-emergent, POEM= post-emergent

Number of tuber

Number of tuber is a factor which directly affects the yield. Significant difference was found in data of number of tubers as shown in Table 3. For five plants selected from each plot at harvest, treatment T_2 i.e. Pendimethalin 350 g ha^{-1} as pre-emergent application showed highest tuber count (13) followed by treatment T_3 i.e. Metribuzin 350 g ha^{-1} as post-emergent application (10.33). Treatment T_1 i.e. weedy check showed least tuber count among all the treatments (5.33).

Table 5: Number of tubers as influenced by various treatments

	Treatments	Number of tubers at harvest
T_1	Weedy check	19.33
T_2	Pendimethalin 350 g ha^{-1} as PE	32.00
T_3	Metribuzin 350 g ha^{-1} as POEM	30.33
T_4	Clodinafop 60 g ha^{-1} as POEM	29.00
T_5	Clodinafop + Metribuzin 195 g ha^{-1} as POEM	29.33
T_6	Clodinafop + Metribuzin 260 g ha^{-1} as POEM	28.33
T_7	Paddy straw mulch 6 t ha^{-1}	27.66
T_8	Hand weeding	25.33
	SEm±	1.185
	CD (*P*=0.05)	2.08

Note: PE= pre-emergent, POEM= post-emergent

Number of leaves per m^2

As depicted in Table 4 difference of number of leaves per meter square was found to be significant. After 60 days of planting maximum leaves per m2 was recorded from treatment T_4 i.e. Clodinafop 60 g ha-1 as post-emergent application (302.00 per m^2) followed by treatment T_5 i.e. Clodinafop+ Metribuzin 260 g ha^{-1} as Post-emergent application (300.66 per m^2). Least amount of leaves per m^2 was recorded from treatment T_1 i.e. weedy check (277.33 per m^2). Similarly, maximum leaves per m^2 at harvest was observed in treatment T_4 i.e., Clodinafop 60 g ha-1 as post-emergent application (321.66 per m2) followed by treatment T_6 i.e. Clodinafop+ Metribuzin 260 g ha-1 as post-emergent application (317.00 per m^2). Minimum leaves per m2 at harvest was recorded from treatment T_1 i.e. weedy check (297.00 per m^2).

Table 6: Number of leaves of potato (per m2) as influenced by various treatments

	Treatments	At 60 DAP	At harvest
T_1	Weedy check	277.33	297.00
T_2	Pendimethalin 350 g ha^{-1} as PE	298.66	310.66
T_3	Metribuzin 350 g ha^{-1} as POEM	299.33	316.00
T_4	Clodinafop 60 g ha^{-1} as POEM	302.00	321.66
T_5	Clodinafop+ Metribuzin 195 g ha^{-1} as POEM	297.66	316.33
T_6	Clodinafop+ Metribuzin 260 g ha^{-1} as POEM	300.66	317.00
T_7	Paddy straw mulch 6 t ha^{-1}	296.66	309.33
T_8	Hand weeding	295.33	313.00
	SEm±	2.83	2.60
	CD (*P*= 0.05)	4.98	4.57

Note: PE= pre-emergent, POEM= post-emergent

Crop yield

The data related to crop yield have been shown in Table 5 showed that highest yield was recorded from treatment T_2 i.e., Pendimethalin 350 g ha^{-1} as pre-emergent application (17.08 t ha^{-1}) followed by treatment T_3 i.e., Metribuzin 350 g ha^{-1} as post-emergent application (15.41 t ha^{-1}). Lowest yield was recorded from treatment T_1 i.e. weedy check (8.58 t ha^{-1}). Similarly, Bhan *et al*. (1971) noticed that 75 % of all the weed species emerged during 30 DAP. Hammerton (1974) reported that when weeds were allowed to grow up to 40 DAP, they significantly reduced the yield in Potato. Anon (1992) weed control through hand weeding twice recorded lower Potato yield (323.3 quintal per ha^{-1}) over the weed control by pre-emergence application of Pendimethalin at 1.0 Kg ha^{-1} (353.70 Q ha^{-1}). Jaiswal (1992) [1] reported that maximum reduction in tuber yield by 37 Quintal ha^{-1} was recorded if weeding was delayed from 25-35 days of crop indicating that this period is most critical for crop weed competition. Sekhawat and Maliwal (1992) reported that hand weeding recorded 2.2 ton ha^{-1} increase in tuber yield of Potato over the unweeded control**.** Lal (1993) [4] reported that weedy check treatment reduced the tuber yield in Potato by 53 Q ha^{-1} over weed free condition through hand weeding. However, Biswajit *et al*. (2012) revealed that the maximum N, P_2O_5 and K_2O uptake by Potato (91.03, 31.54 and 132.45 Kg per Hectare respectively) and the minimum uptake of N, P_2O_5 and K_2O by weeds (19.43, 10.44 and 91.33 Kg per Hectare respectively) emerged in Potato field were recorded under the treatment T_3 (hand weeding at 20 DAP along with Mulching) which was closely followed by the treatment T_9 (Pendimethalin @1 Kg a.i. per Hectare along with Mulching).

Table 7: Yield (t ha^{-1}) of potato as influenced by various treatments

	Treatments	Yield (t ha^{-1})
T_1	Weedy check	8.58
T_2	Pendimethalin 350 g ha^{-1} as PE	17.08
T_3	Metribuzin 350 g ha^{-1} as POEM	15.41
T_4	Clodinafop 60 g ha^{-1} as POEM	13.16
T_5	Clodinafop+ Metribuzin 195 g ha^{-1} as POEM	13.85
T_6	Clodinafop+ Metribuzin 260 g ha^{-1} as POEM	14.75
T_7	Paddy straw mulch 6 t ha^{-1}	12.94
T_8	Hand weeding	11.38
	SEm±	
	CD (*P*=0.05)	

***Note*:** PE= pre-emergent, POEM= post-emergent

Economics

Highest cost of cultivation was recorded from treatment T_7 i.e. Paddy straw mulch (₹ 90366 ha^{-1}) while lowest cost of cultivation was recorded treatment T_1 i.e. weedy check (₹ 72366 ha^{-1}) closely followed by treatment T_4 i.e. Clodinafop @60 g ha^{-1} (₹ 72426 ha^{-1}) as Post-emergent application. However, treatment T_2 i.e. Pendimethalin @350 g ha^{-1} as pre-emergent application gave the maximum gross returns (₹ 341667 ha^{-1}) followed by treatment T_3 i.e. Metribuzin @350 g ha^{-1} as post-emergent application (₹ 308333 ha^{-1}). Treatment T_1 i.e. weedy check gave lowest gross returns (₹ 171667 ha^{-1}). Although, treatment T_2 i.e. Pendimethalin @350 g ha^{-1} as pre-emergent application gave maximum net returns (₹ 269181 ha^{-1}) followed by treatment T_3 i.e. Metribuzin @350 g ha^{-1} as post-emergent herbicides (₹ 235652 ha^{-1}). Treatment T_1 i.e. weedy check gave minimum net returns (₹ 99300 ha^{-1}) followed by treatment T_8 i.e. hand weeding (₹ 145300 ha^{-1}). In nutshell, Treatment T_2 recorded highest B: C ratio of 3.71 followed by treatment T_3 i.e. Metribuzin @350 g ha^{-1} as post- emergent application (3.24). Treatment T_1 i.e. weedy check recorded lowest B: C ratio of 1.37. Shekawat and Maliwal (1991) observed that weed control through either Pendimethalin or hand weeding at 30 days after planting in Potato was the most economic practices.

Table 8: Economics of potato cultivation as influenced by various treatments

Treatments		Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T_1	Weedy check	72366	171667	99300	1.37
T_2	Pendimethalin @350 g ha^{-1} as PE	72485	341667	269181	3.71
T_3	Metribuzin @350 g ha^{-1} as POEM	72681	308333	235652	3.24
T_4	Clodinafop @60 g ha^{-1} as POEM	72426	263333	190907	2.63
T_5	Clodinafop +Metribuzin @195 g ha^{-1} as POEM	72551	277166	204615	2.82
T_6	Clodinafop+ Metribuzin @260 g ha^{-1} as POEM	72613	295000	222387	3.06
T_7	Paddy straw mulch @6 t ha^{-1}	90366	258833	168467	1.86
T_8	Hand weeding	82366	227667	145300	1.76

Note: PE= pre-emergent, POEM= post-emergent

Conclusion

From the results of the experiment conducted, it can be concluded that Weed dry matter and weed density significantly decreased due to application of herbicides. Yield of potato also increased significantly due to low weed density and hence, weed management treatments influenced the yield indirectly. Pendimethalin 350 g ha^{-1} as pre-emergent application was most superior in controlling weeds when compared to other treatments. Hence, it also gave the maximum yield of Potato. Treatment T_1 i.e. weedy check was least efficient in controlling weeds and gave the lowest yield. Treatment T_2 gave the maximum profits among all the treatments from farmer's perspective.

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