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Efficacy of Different Herbicides for Controlling Grass Predominant Weed Flora and Achieving Higher Production in Dual Purpose Linseed under Mid Hills of Himachal Pradesh

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ABSTRACT

A field experiment was conducted to study the effect of herbicide treatments on the weed flora and the production of the dual-purpose Linseed. The results revealed that grassy weeds viz., *Phalaris minor, Lolium temulentum* and *Avena ludoviciana* constituted 43.2, 23.2 and 17.2% of the total weed flora at 90 DAS. Among the broadleaf weeds, *Vicia sativa* and *Spergulla arvensis* constituted about 8.4% of total weed flora. As the crop was mainly infested with grassy weeds, effective control of total weeds with the application of clodinafop 60 g/ha (Post.), pendimethalin 1.0 kg/ha (Pre.) and isoproturon 1.25 kg/ha (Post.) as equivalent to hand weeding twice resulted in significantly higher seed, straw, biological, oil and fibre yield of Linseed. As far as the economics is concerned, significantly higher net returns of ₹ 54401 and 3051/ha and net returns per rupee invested (2.01 and 1.90) were obtained by statistically similar treatments of clodinafop 60 g/ha (Post.) and pendimethalin 1.0 kg/ha (Pre.), respectively. Thus, depending upon the situation in dual-purpose Linseed, selecting either of these appropriate chemicals is the better option for controlling grass-predominant weed flora and obtaining higher yields (seed and fiber) with better returns.

Keywords Economics, dual-purpose Linseed, fiber, oil, weed control, yield.

INTRODUCTION

Linseed (*Linum usitatissimum* L.) is a traditional *rabi* oilseed crop belonging to the family *Linaceae*. It is of tremendous economic importance because of its medicinal and industrial value for the quality of the oil. The wider adaptability of the crop to the varying environmental conditions makes it an appropriate choice for alternative cropping systems. The crop can sustain its growth under conserved moisture and limited nutrient conditions of the soil. In the world, the area under Linseed is 3.54 Mha, with a production of 3.37 Mt and productivity of 951.2 kg ha^{-1} (FAO 2022), while in India, it occupies an area of 1.7 lakh ha with

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a production and productivity of about 1 lakh tonnes and 574 kg ha^{-1}, respectively. India holds fifth position in the area after Kazakhstan, the Russian Federation, Canada, and China but ranks sixth in production after Kazakhstan, Canada, the Russian Federation, China, and the USA (FAO 2022). In Himachal Pradesh, Linseed has an estimated area of 0.70 thousand ha with production and productivity of 0.24 thousand tonnes and 334 kg/ha, respectively (DESASD 2022). It is a great source of nutrients and contains 33 to 47% oil. The oil is used in cooking and for industrial uses like manufacturing paints, stains, inks, varnishes. The oil is rich in linolenic acid (>66%) and also contains high levels of dietary fiber, lignin, and omega-3 fatty acids (Gill 1987). It contains 36% protein, 85% of which is digestible (Muir and Westcott 2003). After oil extraction, linseed cake may be used as organic manure because it contains about 5% N, 1.4% P_2O_5, and 1.8% K_2O (Ganvit *et al.* 2019). Apart from these, the fiber extracted especially from dual-purpose and flex types linseed has many industrial uses such as in manufacturing ropes, fabrics, especially linen, currency notes, rolling paper for cigarettes, moulded panels, insulation material. The linseed fiber is the oldest fiber obtained from the straw of crop after silk. Therefore, the focus is increasingly shifting toward the dual-purpose Linseed, which yields both seed and fiber without compromising the seed yield (Rennebaum *et al*. 2002).

Crop production is the function of light, water, CO_2, space, nutrients. The competition of the crop with these factors determines the overall production. Weed management plays a significant role in maintaining and enhancing crop production and influences the quality of the oil and fiber in dual-purpose linseed. Due to its poor initial growth and lower canopy spread because of its small-sized leaves, Linseed is more prone to losses (30-40%) due to weed infestation (Hussein *et al.* 2000, Derksen and Wall 1996, Mahere *et al.* 2000). The conventional method of weed control includes hand weeding and inter-culturing between the rows. Though conventional methods have the highest weed control efficiency, they have proven to be laborious and time-consuming (Acharya *et al.* 2017, Singh *et al.* 2020). Therefore, using herbicides may be a suitable alternative for managing weeds for higher returns (Singh *et al.* 2019).

MATERIALS AND METHODS

A field experiment was conducted to evaluate the efficacy of different herbicides either applied solely or in combination on the weed population in Linseed at the Experimental Farm, Department of Crop Improvement, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (HP) during the rabi season of 2013-14. The experiment was laid out in a randomized block design with twelve treatments and three replications. The variety of Linseed was "Nagarkot". The treatments are: T_1: Clodinafop @60 g/ha, T_2: Imazethapyr @75 g/ha, T_3: Imazethapyr @100 g/ha, T_4: Pendimethallin + imazethapyr (ready-mix) @750 g/ha, T_5: Pendimethallin + imazethapyr (ready-mix) @1000 g/ha, T_6: Imazethapyr + imazamox (ready-mix) @40 g/ha, T_7: Imazethapyr + imazamox (ready-mix) @60 g/ha, T_8: Isoproturon + 2,4-D (Na) @1000 + 500 g/ha, T_9: Isoproturon @1250 g/ha, T_{10}: Pendimethallin @1000 g/ha, T_{11}: Hand weeding twice at 30 and 50 DAS and T_{12}: Weedy Check. The experimental site was at 32o6' N latitude, 76o3' E longitude and an altitude of 1290 m AMSL. Agro-climatically, the experimental site falls under the sub-temperate humid zone of Himachal Pradesh. The soil under study is acidic in reaction with pH 5.7 and silty clay loam texture. The soil was low in available nitrogen (276.7 kg/ha), medium in phosphorus (14.82 kg/ha), and medium in potassium (186.7 kg/ha). The crop variety 'Nagarkot' was sown at 23 cm apart rows using a seed rate of 40 kg/ha. The crop was supplied with 50, 40, and 20 kg N, P_2O_5 and K_2O/ha. The pre-emergence herbicides were applied immediately after sowing, while post-emergence herbicides were applied at 2-3 leaf stage of weeds. A knapsack sprayer fitted with a flat fan nozzle using 700 liters of water per hectare was used for spraying the herbicide. Data on density and dry weight of total weeds were recorded at their maximum population and dry matter stage, i.e., 90 DAS, subjected to square root transformation. The weed control efficiency was calculated as per formulae given by Mani *et al.* (1973).

$$WCE = \frac{DMC\text{-}DMT}{DMC} \times 100$$

Where DMC= Dry matter of weeds in control (unweeded) treatment,

DMT-Dry matter of weeds in a treatment.

Linseed's seed, straw, and biological yield was recorded at harvest from the net plot area and expressed in kg/ha. The harvest index was determined by working out the ratio of seed to biological yield of individual plots. The oil content in seeds was determined by using ether as a solvent by the method given in AOAC (AOAC 1970). Oil yield was calculated by multiplying the oil content of individual treatments with the respective seed yield.

After extracting seeds, the straw obtained from each net plot was further processed for retting. Thereafter, it was sun-dried and weighed to obtain a retted straw yield. The fiber obtained from the net plot after scutching the retted straw was cleaned with the help of fiber cleaning machine, and the weight obtained was converted to kg/ha.

The length of every unbroken reed (the entire length of the fiber system) obtained from five sampled plants was measured in centimeters. The total length was divided by the number of reeds to get the mean fiber length.

For fiber percentage, five plants were sampled. The sun-dried weight of retted straw and fiber obtained from them was recorded and calculated per the formula below.

$$\text{Fiber percentage} \; \frac{\text{Weight of fiber (g)}}{\text{Weight of retted straw (g)}} \times 100$$

The economics of the treatments was computed based on prevalent market prices.

RESULTS AND DISCUSSION

Weed flora: The experimental field was continuously monitored for the occurrence of weed species. The surveillance data at 90 DAS revealed that *Phalaris minor, Lolium temulentum* and *Avena ludoviciana* were the major grassy weeds (43.2, 23.2 and 17.2% of total weed flora, respectively). Among the broadleaf weeds, *Vicia sativa* and *Spergulla arvensis* were the major weeds, constituting 3.1 and 5.3% of the total weed flora, respectively. During the study, the other weed species that infested the crop were *Poa annua, Oxalis latifolia, Alopecurus myosuroides*, and *Briza minor* (Table 1).

Table 1. Species wise population of weeds in weedy check at maximum population stage (i.e. 90 DAS).

Weed species	Population (No./m^2)	Percentage of of total
Phalaris minor	174.00	43.2
Lolium temulentum	93.33	23.2
Avena ludoviciana	69.33	17.2
Vicia sativa	12.67	3.1
Spergulla arvensis	21.33	5.3
Other weeds	32.00	7.9
Total	402.66	100

Total weed count and dry matter: Various weed control treatments significantly influenced the weed count and weed dry matter. Total weed count varied from 5.86 to 20.08/m^2, while weed dry matter varied from 6.51 to 14.47 g/m^2. Significantly superior weed control was recorded for hand weeding with the lowest weed count (5.86/m^2) and dry matter (6.51 g/m^2) among various weed control treatments (Table 2). Hand weeding with the elimination of most of the above-ground weed biomass at 30 and 50 DAS effectively controlled the weed complex and thus significantly reduced total weed count and dry matter. Among herbicide-based treatments, clodinafop 60 g/ha (Post.) was observed to be the most effective in terms of reducing the total weed count (7.28/m^2) and dry matter (7.18 g/m^2) and was statistically at par with pendimethalin 1.00 kg/ha (Pre.) (7.26/m^2 and 7.58 g/m^2, respectively), isoproturon 1.25 kg/ha (Post) (7.95/m^2 and 7.42 g/m^2, respectively) and imazethapyr + imazamox 60 g/ha (Post) (8.14/m^2 and 7.80 g/m^2, respectively).

Clodinafop, with its inhibitory effect on acetyl CoA carboxylase kept the weed population under control. Clodinafop 60 g/ha (Post.) based suppression of weed count and dry matter in Linseed has already been well documented (Badiyala and Chopra 2010). The superior performance of pendimethalin 1.0 kg/ha (Pre.) with its inhibiting effect on cell division and cell elongation responsible for the death of weeds shortly after germination has been observed earlier by various researchers (Jain *et al.* 2016, Mahajan and Khande 2020). The highest total weed count (20.08) and dry weight (14.47) were recorded for the weedy check tailgated by imazethapyr 75 g/ha (Post) with weed count of 17.52 and weed dry matter, 12.15 (Table 2).

Table 2. Influence of weed control treatments on weed count, dry matter and weed control efficiency.

Treatment	Total weed count (90 DAS) (No./m^2)	Total weed dry weight (150 DAS) (g/m^2)	Weed control efficiency (%)
T_1: Clodinafop 60 g/ha (Post.)	7.28 (52.66)	7.18 (50.54)	75.8
T_2: Imazethapyr 75 g/ha (Post.)	17.52 (306.67)	12.15 (146.69)	29.7
T_3: Imazethapyr 100 g/ha (Post.)	11.57 (133.33)	9.83 (95.67)	54.2
T_4: Pendimethalin + imazethapyr 0.75 kg/ha (Pre.)	15.75 (248.00)	11.58 (133.38)	36.1
T_5: Pendimethalin + imazethapyr 1.00 kg/ha (Pre.)	8.23 (68.00)	8.17 (66.18)	68.3
T_6: Imazethapyr + imazamox 40 g/ha (Post.)	14.62 (212.67)	10.89 (117.75)	43.6
T_7: Imazethapyr + imazamox 60 g/ha (Post.)	8.14 (65.33)	7.80 (59.93)	71.3
T_8: Isoproturon + 2,4-D (Na) 1.0 +0.5 kg/ha (Post.)	10.99 (120.00)	9.66 (92.33)	55.8
T_9: Isoproturon 1.25 kg/ha (Post.)	7.95 (62.67)	7.42 (54.28)	74.0
T_{10}: Pendimethalin 1.00 kg/ha (Pre.)	7.26 (52.00)	7.58 (56.65)	72.9
T_{11}: HW twice at 30 and 50 DAS	5.86 (33.33)	6.51 (41.68)	80.0
T_{12}: Weedy check	20.08 (402.67)	14.47 (208.76)	0.0
CD (p=0.05)	1.33	0.74	

Values given in parenthesis are the means of original values.

Weed control efficiency: Weed Control efficiency ranged between 36.1% to 80% for weed control treatments (Table 2). The magnitude of weed control was recorded to be the highest for hand weeding (80%), whereas the lowest was for pendimethalin + imazethapyr 0.75 kg/ha (Pre.) (36.1%). Hand-weeding practices being uneconomical over extended farm sizes are impractical and are replaced by herbicide-based weed control. Clodinafop 60 g/ha (Post.) (75.8%) was the most suitable candidate for chemical weed control with its considerably better weed control efficiency among herbicide-based treatments.

Yield (seed, straw, biological and oil) and harvest index: A significant influence of weed control treatments was observed on Linseed's seed yield and biological yield (Table 3). Seed yield ranged from 708.53 kg/ha to 1363.39 kg/ha for various tested treatments. Clodinafop 60 g/ha (Post.) -based weed control (1320.45 kg/ha) resulted in a significantly higher seed yield of Linseed and was at par with hand weeding (HW) twice at 30 and 50 DAS (1341.92 kg/ha), pendimethalin (1363.39 kg/ha) and isoproturon 1.25 kg/ha (Post.) (1277.51 kg/ha). Efficient weed control with these herbicides considerably reduced the competition for growth factors such as water and nutrients by weeds, resulting in a better yield response. Such an impact of clodinafop 60 g/ha (Post.) and isoproturon 1.25 kg/ha (Post.) over linseed yield was also observed by Angiras *et al.* (1991), Badiyala *et al.* (1997) and Husain *et al.* (2003). Among herbicide-based weed control treatments, imazethapyr 75 g/ha (Post.) (933.98 kg/ha) and pendimethalin + imazethapyr 75 g//ha (Pre.) (1019.86 kg/ha) had a poor response in terms of weed control and were unable to provide linseed optimum weed free environment for higher yield. However, the susceptibility of Linseed to weed competition was considerably

Table 3. Influence of weed control treatments on crop, oil yield and harvest index.

Treatments	Seed yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)	Oil yield (kg/ha)
T_1: Clodinafop 60 g/ha (Post.)	1320.45	6763.29	19.53	537.51
T_2: Imazethapyr 75 g/ha (Post.)	933.98	4991.95	18.82	372.02
T_3: Imazethapyr 100 g/ha (Post.)	1164.79	6119.16	19.08	465.43
T_4: Pendimethalin + imazethapyr 0.75 kg/ha (Pre.)	1019.86	5421.36	18.83	405.56
T_5: Pendimethalin + imazethapyr 1.00 kg/ha (Pre.)	1229.20	6226.51	19.77	491.95
T_6: Imazethapyr + imazamox 40 g/ha (Post.)	1105.74	5750.78	19.26	400.65
T_7: Imazethapyr + imazamox 60 g/ha (Post.)	1154.05	5856.13	19.79	420.27
T_8: Isoproturon + 2,4-D (Na) 1.0 +0.5 kg/ha (Post.)	1170.15	6099.16	19.28	448.85
T_9: Isoproturon 1.25 kg/ha (Post.)	1277.51	6246.51	20.46	469.25
T_{10}: Pendimethalin 1.00 kg/ha (Pre.)	1363.39	6655.93	20.49	550.86
T_{11}: HW twice at 30 and 50 DAS	1341.92	6521.74	20.57	550.04
T_{12}: Weedy check	708.53	3757.38	18.86	274.99
CD (p=0.05)	101.25	621.90	NS	42.08

highlighted under weedy check (708.53 kg/ha) due to unhindered weed growth resulting in a steep decline in seed yield by 42.3 to 48.0% as opposed to other herbicide-based and hand-weeding-based weed control treatments where the decline in yield was up to 47.2%.

Biological yield varied from 3757.38 kg/ha to 6763.29 kg/ha for the treatments under study. The biological yield was considerably higher for pendimethalin 1.00 kg/ha (Pre.), which was statistically at par with HW twice at 30 and 50 DAS (6521.74 kg/ha), clodinafop 60 g/ha (Post.) (6763.29 kg/ha), isoproturon 1.25 kg/ha (Post.) (6246.51 kg/ha) and pendimethalin + imazethapyr 1.00 kg/ha (Pre.) (6226.51 kg/ha). The better weed control allowed the crops to accumulate more photosynthates, resulting in significantly higher biomass. High weed growth, especially under weedy check (3757.38 kg/ha), had a negative impact on biomass accumulation, resulting in 80, 77.1, and 73.6% losses compared to clodinafop 60 g/ha (Post.), pendimethalin (Pre.) 1.0 kg/ha and hand weeding performed twice at 30 and 50 DAS, respectively.

All the weed control treatments were significantly superior over the weedy check in influencing the oil yield of Linseed. Pendimethalin 1.0 kg/ha (Pre.), hand weeding twice, and clodinafop 60 g/ha (Post.) being at par with each other, emerged as the best treatments for recording significantly higher oil yield (550.86, 550.04 and 537.51 kg/ha, respectively). Pendimethalin + imazethapyr 1.0 kg/ha (Pre.) with an oil yield of 491.95 kg/ha was the other best treatment in this regard, which was also at par with isoproturon 1.25 kg/ha (Pre.), and imazethapyr 100 g/ha (Post.) (469.25 and 465.43 kg/ha, respectively). Unchecked weed growth in the weedy check reduced the oil yield to 100.32% compared to the best treatment.

Harvest index, being a genotypic character, did not receive any significant influence by weed control treatments. However, hand weeding (20.57 %), clodinafop 60 g/ha (Post.) (19.53 %), pendimethalin 1.0 kg/ha (Pre.) (20.49 %), and isoproturon 1.25 kg/ha (Post.) (20.46 %) based treatments were observed to have slightly higher harvest index over rest of the treatments (Table 3).

Post-harvest studies

Retted straw yield: The retted straw yield of the Linseed was significantly influenced by the various herbicide treatments under study. The retted straw yield of 3197.61 kg/ha was highest for clodinafop 60 g/ha (Post.) based weed control (Table 4). The positive impact on retted straw yield might be due to substantially higher biological yield and negative influence over weed growth. However, a par performance w.r.t. to retted straw yield was recorded for pendimethalin 1 kg/ha (Pre.) (3161.60 kg/ha), HW twice at 30 and 50 DAS (3105.34 kg/ha), isoproturon 1.25 kg/ha (Post.) (3008.97 kg/ha) and pendimethalin

Table 4. Influence of weed control treatments on retted straw yield, fiber yield and fiber quality.

Treatments	Retted straw yield (kg/ha)	Fiber percent (%)	Total fiber yield (kg/ha)	Effective reed length (cm)	Fiber length (cm)
T_1: Clodinafop 60 g/ha (Post.)	3197.61	27.31	873.74	65.96	61.07
T_2: Imazethapyr 75 g/ha (Post.)	2279.23	23.37	532.13	59.77	54.85
T_3: Imazethapyr 100 g/ha (Post.)	2678.87	24.14	648.21	61.38	56.36
T_4: Pendimethalin + imazethapyr 0.75 kg/ha (Pre.)	2576.09	23.59	605.96	61.13	55.02
T_5: Pendimethalin + imazethapyr 1.00 kg/ha (Pre.)	2855.34	24.48	698.01	62.07	57.27
T_6: Imazethapyr + imazamox 40 g/ha (Post.)	2655.50	24.06	638.83	61.27	56.08
T_7: Imazethapyr + imazamox 60 g/ha (Post.)	2716.51	24.61	670.59	60.56	55.47
T_8: Isoproturon + 2,4-D (Na) 1.0 +0.5 kg/ha (Post.)	2715.97	25.43	689.12	61.09	56.51
T_9: Isoproturon 1.25 kg/ha (Post.)	3008.97	25.85	778.66	61.59	56.66
T_{10}: Pendimethalin 1.00 kg/ha (Pre.)	3161.60	26.90	850.66	62.14	57.64
T_{11}: HW twice at 30 and 50 DAS	3105.34	27.09	841.21	64.83	59.96
T_{12}: Weedy check	1439.90	22.86	329.20	56.67	50.91
CD (p=0.05)	432.97	1.29	114.69	3.94	4.16

+ imazethapyr 1 kg/ha (Pre.) (2855.34 kg/ha). The alone application of imazethapyr 75 g/ha (Post) gave a significantly lower retted straw yield (2279.23 kg/ha) followed by pendimethalin + imazethapyr 0.75 kg/ha (Pre.) (2678.87 kg/ha). Weedy check with the lowest biological yield and no check over weed growth resulted in the lowest retted straw yield (1439.90 kg/ha).

Total fiber yield and fiber percent: The fiber yield and fiber percent followed a similar pattern to the retted straw yield (Table 4). A significantly higher fiber yield was recorded for Clodinafop 60 g/ha (Post.) (873.74 kg/ha) which was at parity with pendimethalin 1.00 kg/ha (Pre.) (850.66 kg/ha), HW twice at 30 and 50 DAS (841.21 kg/ha) and isoproturon 1.25 kg/ha (Post.) (778.66 kg/ha). It might be due to substantially higher retted straw yield under these herbicide-based weed control treatments. Corresponding to the lowest straw yield and fiber percentage, a weedy check with maximum weed hindrance resulted in the linseed crop's lowest fiber yield (329.20 kg/ha).

Fiber percentage varied from 22.86 to 27.31%. The highest percent fiber was recorded for clodinafop 60 g/ha (Post.) (27.31%) and was statistically at par with HW twice at 30 and 50 DAS (27.09%) and pendimethalin 1 kg/ha (Pre.) (26.90%). Superior performance for fiber percentage with these herbicides might be due to reduced weed competition under these treatments, enhancing the crop quality due to better availability of resources for crop growth. Imazethapyr + imazamox 40 g/ha (Post.) (24.06%), imazethapyr @75 g/ha (Post.) (23.37%), and 100 g/ha (Post.) (24.14%) based application, however, was unable to exert any significant influence on fiber percentage and resulted in fiber proportion that was at par with treatment where there was no check on weed growth (22.86%). The fiber percentage of the retted straw yield mainly contributed to the fiber yield of the crop (Mańkowski *et al.* 2015).

Fiber length and effective reed length: Effective reed length and fiber length of treatments, weedy check, and imazethapyr 75 g/ha (Post.) did not differ significantly (Table 4). The application of imazethapyr @75 g/ha was ineffective in controlling the weed flora, resulting in lower effective reed and fiber length. Significantly longer effective reed length (65.96 cm) and fiber length (61.07 cm) were reported for clodinafop 60 g/ha (Post.), i.e., the clodinafop-based application was able to keep linseed crop in good condition, resulting in the longest effective reed and fiber for the crop. Weeds compete with crop plants to receive more and more sunlight for photosynthesis. The negative impact of weed competition can reduce crop height and thus reduce linseed crops' effective reed and fiber length (Mańkowski *et al.* 2015). Clodinafop @ 60 g/ha (Post.) positively controlled weeds, resulting in better effective reed and fiber length. HW

Table 5. Influence of weed control treatments on economics of linseed production.

Treatments	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	BC ratio
T_1: Clodinafop 60 g/ha (Post.)	23916	78317	54401	2.01
T_2: Imazethapyr 75 g/ha (Post.)	24092	51995	27903	0.97
T_3: Imazethapyr 100 g/ha (Post.)	24525	63900	39374	1.39
T_4: Pendimethalin + imazethapyr 0.75 kg/ha (Pre.)	24231	57946	33714	1.18
T_5: Pendimethalin + imazethapyr 1.00 kg/ha (Pre.)	24711	68048	43336	1.52
T_6: Imazethapyr + imazamox 40 g/ha (Post.)	23592	61825	38233	1.40
T_7: Imazethapyr + imazamox 60 g/ha (Post.)	23992	64569	40577	1.47
T_8: Isoproturon + 2,4-D (Na) 1.0 +0.5 kg/ha (Post.)	24750	65761	41010	1.44
T_9: Isoproturon 1.25 kg/ha (Post.)	23625	71988	48362	1.79
T_{10}: Pendimethalin 1.00 kg/ha (Pre.)	24838	77890	53051	1.90
T_{11}: HW twice at 30 and 50 DAS	30572	77380	46808	1.33
T_{12}: Weedy check	22072	35887	13815	0.50
CD (p=0.05)		5847	5847	0.21

twice at 30 and 50 DAS (64.83 and 59.96 cm, respectively), pendimethalin 1 kg/ha (Pre.) (62.14 and 57.64 cm, respectively), and pendimethalin + imazethapyr 1 kg/ha (Pre.) (62.07 and 57.27 cm, respectively) based weed control was observed to be as statistically as efficient as clodinafop 60 g/ha (Post.) in maintaining effective reed and fiber length.

Economic studies: Weed control treatments significantly affected the gross returns, net returns, and benefit-cost ratio (Table 5). Clodinafop 60 g/ha (Post.) was found to be the most economical herbicide with significantly higher net returns (54401 ₹/ha) and profit generated per rupee invested (2.01) as compared to other weed control treatments. The utility of clodinafop for significantly higher income generation was also reported by Kumar and Nagaich (2013). Pendimethalin was at par with clodinafop 60 g/ha (Post.) in terms of net returns (53051 ₹/ha) and benefit-cost ratio (1.90). The potential of pendimethalin in enhancing net returns for linseed cultivation was also reported by Acharya *et al*. (2017). Net returns and benefit-cost ratio declined to ₹13815/ha and 0.50, respectively, with weedy checks or where no appropriate weed control measures were undertaken. In herbicide-based treatments, the lowest net returns and BC ratio of ₹27903/ha and 0.75, respectively, were recorded with imazethapyr 0.75 kg/ha (Post.). Hand weeding, despite having significantly superior control over weed flora, resulted in significantly lower net returns (46808 ₹/ha) and a benefit-cost ratio 1.33. The central reason for lower returns was higher labor requirements for hand-weeding practices than herbicide-based weed control (Dwivedi and Puhup 2019).

CONCLUSION

Susceptibility to weed competition and dynamic weed flora for linseed crops make herbicide-based weed control a must practice for higher productivity and quality of the crop. Conventional methods, such as hand weeding, reported significantly better yield and quality but were uneconomic due to high labor requirements. For such purpose, the present study concluded clodinafop 60 g/ha (Post.) and pendimethalin 1 kg/ha (Pre.) application-based weed control as suitable practices for efficient and economical weed control in Linseed. Imazethapyr at lower doses (75 g/ha), however, could not exert any significant influence on linseed productivity and quality and performed at par with conditions wherein weed flora had unchecked growth.

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