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RESEARCH ARTICLE

Bio-efficacy of sequential herbicide application on weed control and yield of field-pea under temperate conditions of Kashmir

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ABSTRACT

A field experiment was conducted at Agronomy Research Farm, Division of Agronomy, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura during *Rabi* seasons of 2021-22 and 2022-23 to study the effect of sequential application of herbicides on weeds and yield of field-pea under temperate conditions. The experiment consisted of 14-treatments which were tested in a complete randomized design replicated thrice. Weeds caused 63.8 and 61.0 per cent reduction in seed yield of field pea during 2021-22 and 2022-23, respectively. Among the herbicides tested, pre-emergence application of pendimethalin 1.00 kg/ha followed by post-emergence application of imazethapyr 0.125 kg/ha recorded significantly lowest weed biomass, weed index and highest weed control index, field-pea growth and yield attributes, seed and stover yield, and better economics over the rest treatments. Hand weeding recorded higher growth and yield of field pea but it was not cost-effective.

Keywords: Economics, Field pea, Imazethapyr, Pendimethalin, Weed management

INTRODUCTION

Field pea (*Pisum sativum* L.) is one of the most important *rabi* season pulse crop in Northern and Central parts of India. Its cultivation maintains soil fertility by enabling biological nitrogen fixation through a symbiotic relationship with *Rhizobium* bacteria found in its nodules, therefore contributing significantly to sustainable agriculture (Negi *et al*. 2006). In India, field pea is cultivated in an area of 0.64-million-hectare with an annual production of 0.88 million tons and an average productivity of 1.4 tons/ha (IIPR 2021). Among the pea growing states, Uttar Pradesh ranks first accounted for 48.33% of peas production in India during 2021-22 followed by Madhya Pradesh with 15.67% of peas production (Numerical 2023). Peas are widely consumed as part of the human diet across the globe and are a rich source of protein (21-25%), carbohydrates (42.65%), vitamin A & C, calcium, phosphorus and essential amino acids such as lysine and tryptophan (Bhat *et al*. 2013). Pea has great potential for grain as well as vegetable purposes. Peas are consumed as a vegetable in fresh, frozen or canned form during the off-season and are also cultivated for producing dry peas, such as split peas. The dried grains are used in various forms including snacks like chat and chhola as well as in dal, flour and other culinary dishes and constitutes an important food supplement for the majority vegetarian population of India.

The quality and productivity of peas tend to reduce due to various biotic and abiotic factors. Among the several factors, competition between crops and weeds is the most serious. Peas compete poorly with weeds because of their slow growth at the early stages and short stature, resulting in huge yield loss (Chaudhary *et al*. 2009). Peas face intense crop weed competition up to 60 days after seeding (DAS) (Kumar *et al*. 2014) which can reduce yields ranging from 40 - 70% (Harker 2001). Peas are vulnerable to grasses, broad-leaved weeds and sedges, resulting in significant yield loss and quality. In addition, late season weeds can decrease harvest efficiency and reduce the quality of pea grains (Singh and Survey 2016). For the control of weeds, generally farmers adopt manual or hand weeding (Singh and Wright 2006) but it is labor-intensive, time consuming and un-economical and hence farmers tend to opt for alternative, cheaper and easier methods of chemical weed control for controlling different types of weeds. Pre-emergence application (PE) of pendimethalin 1.00 kg/ha, is a selective and

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effective herbicide used in pea against annual grasses and few broad-leaved weeds. However, only pre-emergence applications are not adequate to control diverse weeds, which differ in physiology, morphology and tolerance. Continuous use of single herbicide may also favour weed shifts and resistance. Brijbhooshan *et al*. (2017) reported that pendimethalin at 1.00 kg/ha PE was inferior to one hand weeding employed at 25 days after sowing (DAS). Besides, during winter, the efficacy of pre-emergence herbicides is greatly affected by the soil surface dryness and change in weather variables namely rainfall, sunshine and humidity. However, post-emergence application (PoE) of herbicides may help growing field pea which is severely infested by weeds even after one month of sowing due to its initial slow growth. Post-emergence herbicide can protect pea crop from weed competition throughout the season. Post-emergence herbicide imazethapyr control weeds in peas led to optimum seed yield (Das 2016). Thus, sequential herbicide applications *i.e*., pre-emergence followed by (*fb*) post-emergence in pea may provide complete control of weeds up to 45-50 days stage after which crop smoothers the weeds and may shift the competition in favour of the crop and prevent weed shift and delay resistance (Das *et al*. 2014).

MATERIALS AND METHODS

The objective of the experiment was to evaluate the efficacy of sequential herbicide application on weeds and field pea crop yield. The experiment was carried out at Agronomic Research Farm, of the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura, India during *Rabi* season of 2021-22 and 2022-23. The soil of the experimental site was silty-clay loam in texture, acidic in reaction (6.4), and medium in available nitrogen (275.5 kg/ha), phosphorus (17.5 kg/ha) and potassium (174.2 kg/ ha). The experiment consisted of 14-treatments, *viz*. pendimethalin (30% EC) (pendimethalin) 1.00 kg/ha PE 2 DAS; oxyfluorfen (23.5% EC) (oxyfluorfen) 0.150 kg/ha PE; pendimethalin 1.00 kg/ha PE *fb* imazethapyr (10% SL) (imazethapyr) 0.025, 0.050, 0.075, 0.100 and 0.125 kg/ha PoE; oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025, 0.05, 0.075, 0.100 and 0.125 kg/ha PoE; pendimethalin 1.00 kg/ha PE *fb* manual weeding twice; oxyfluorfen 0.150 kg/ha PE *fb* manual weeding (HW) twice; weedy check and weed free check (HW at 20 days interval after mid-February) A complete randomized design replicated thrice was used. In Kashmir valley, the field-pea is a winter (*Rabi*) crop with a long duration of 210 days and is subjected to a prolonged period of winter-induced dormancy from late November to February. Due to low temperature the crop exhibits minimal metabolic and vegetative development. With the onset of early spring and the gradual rise in temperature, the plants resume active vegetative growth, typically beginning in the first week of March (at 135 DAS). A pronounced flush of weeds was observed immediately following the crop's dormancy phase, coinciding with the resumption of vegetative growth. So, the post-emergence herbicides were applied during the first week of March when the crop and the newly emerged weeds were at growth stages most responsive to weed control. As rising soil temperatures in the spring stimulate rapid weed growth, the 210-day field pea crop grown in the Kashmir valley, faces a second peak of weed competition in the spring. Hence, the manual weeding at 135 and 160 DAS effectively targets these spring weeds before they can overshadow the pea during their peak flowering and pod-filling stages and also removes the mature winter weeds before they set seeds (shattering) which were suppressed by winter snow. During 2021-22 crop growth period, the temperatures dropped below ^{0}0C from 46- 08 Standard Meteorological week (SMW), and during 2022-23 crop growth period from 47-07 SMW as shown in **Figure 1** and **2** respectively. Manually operated knapsack sprayer fitted with a flat fan nozzle was used for spraying the herbicides. Pendimethalin and oxyfluorfen were applied by spraying, uniformly, at 2 DAS. Imazethapyr was applied during the first week of March *i.e*. 135 DAS when the weeds were at 2-4 leaf stage and also no irrigation was given at the time of imazethapyr application as the soil was having sufficient moisture. The field pea crop (Shalimar pea-1) was sown in rows, 30 cm apart with plant-to-plant distance of 10 cm on 22 October 2021 and 25 October 2022 (43rd Standard Meteorological Weeks) during both the crop growing periods of 2021-22 and 2022-23 respectively by using 80 kg per hectare seed rate. The mean weekly maximum and minimum temperature was 14.4 ^{0}C and 3.6^{0}C, respectively in 2021-22 while 20 ^{0}C and 2.4 ^{0}C in 2022-23, respectively. A total of 544.5 mm and 671.6 mm rainfall was received at experimental site during 2021-22 and 2022-23, respectively. The soil moisture at the time of sowing was sufficient for germination and emergence. At the time of sowing, uniform doses of 45 kg, 70 kg and 40 kg of N, P and K were applied as basal doses through urea, DAP and MOP, respectively. The data recorded for each parameter was subjected to analysis for variance for randomized complete block design. From each experimental plot,

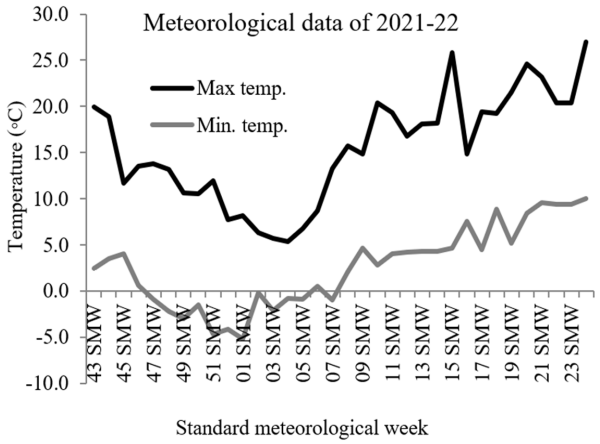

Figure 1. Weather parameter (max. and min. temp.) during crop growth period of 2021-22

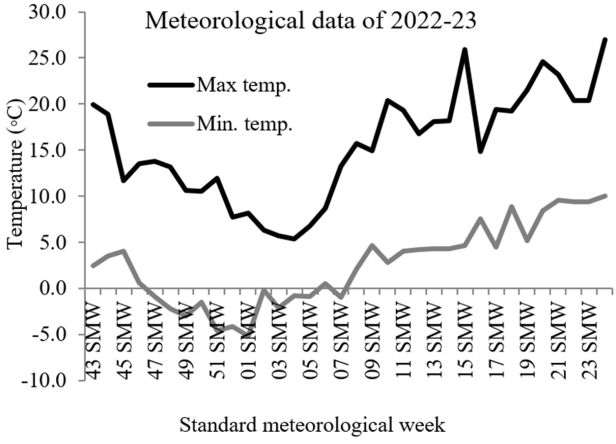

Figure 2. Weather parameter (max. and min. temp.) during crop growth period of 2022-23

five random plants were chosen to record observations on plant height, leaf area index, dry matter accumulation and crop growth analysis at 30 days interval from last week of February (120 DAS) up to harvest. While field-pea yield and yield attributing parameters (number of pods per plant, number of seeds per pod and seed index) were recorded at harvest. For weed population, weed dry matter (biomass) and weed control index, were recorded at 150 DAS and 175 DAS. The weed biomass was recorded using 0.25 m × 0.25 m quadrat placed randomly at five places in each plot and the weeds falling within the frames of the quadrat were uprooted and placed for sun drying. After, sun drying, they were dried in a hot air oven at 65-70 ^{0}C until reaching a constant weight, and the mean values were expressed as weed biomass (g/m^2).

The calculated weed control performance indices include: weed control index and weed index, based on weed biomass and seed yield, respectively.

1. **Weed control index (WCI**) reflects a per cent reduction in weed dry weight by a treatment (Nath *et al.* 2016).

$$WCI\ (\%) = [(WMC - WMT)*100] / WMC.$$

Where, WMC and WMT are the corresponding biomass of weeds in the control and treated plots.

2. **Weed index (WI)** is a measure of the efficacy of a treatment in terms of yield output when compared with weed free treatment. It reflects a per cent yield loss. (Asres and Das 2011).

$$WI\ (\%) = (YF - YT) / YF$$

Where, YF and YT, respectively, stand for yields in weed-free and treated plots.

With the help of the minimum support price and the current market price of the products, the economics of different treatments was also computed. The B:C, which is the ratio of net returns to total cost of cultivation, was determined to evaluate the treatments' economic viability. Prior to statistical analysis, the density and biomass of weeds were subjected to square root transformation using ($\sqrt{x+0.5}$). The data were subjected to analysis of variance and significant differences among treatments were tested by calculating CD at 5% level of significance differences evaluated by using one way ANOVA (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Field-pea growth parameters

The field-pea growth parameters of field-pea were significantly affected by tested herbicide treatments. The oxyfluorfen 0.150 kg/ha PE showed some level of phytotoxicity on field pea which led to reduced field-pea emergence than with pendimethalin 1.00 kg/ha PE. However, after emergence of the crop, no phytotoxicity symptoms were observed on the crop.

Plant height: Field-pea plant height increased continuously with advancement in crop age and reached its maximum at harvesting stage (**Table 1**). At 150 and 180 DAS during both the years, the hand weeding treatments produced significantly taller plants which were at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE and manual weeding twice. At 210 DAS and at harvest, the hand weeding treatments produced significantly taller plants which were at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE. This may be ascribed to less competition from weeds owing to their effective suppression. Similar results were reported by Rana *et al.* (2015).

Leaf area index: Field-pea leaf area index at 150 DAS during both the years were observed highest with the hand weeding treatment which was at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100, 0.125 kg/ha PoE and manual weeding twice (**Table 1**). Similar trend was observed at 180 DAS during the first year of experiment but during second year at 180 DAS, highest leaf area index was observed with hand weeding treatment which was followed by pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100, 0.125 kg/ha PoE. At 210 DAS during both the years, highest leaf area index was observed with hand weeding treatment which were at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE or *fb* manual weeding twice during 2021-22 but during 2022-23, it was at par with pendimethalin 1.00 kg/ha PE *fb* manual weeding twice. At harvest, leaf area index was observed highest with hand weeding treatment during both years but during second year (2022-23) it was at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE. The lowest leaf area index was recorded with weedy check treatment during both the years.

Dry matter accumulation: Field-pea dry matter accumulation was recorded highest with the hand weeding treatment at all the stages of crop growth (**Table 2**). However, during the first year of experiment (2021-22) at 150 and 180 DAS, hand weeding treatment was at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100, 0.125 kg/ha PoE and during second year at 150 DAS, hand weeding was followed by pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE but at 180 DAS, hand weeding treatment was at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE. However, at 210 DAS and at harvest, pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100,

Table 1. Plant height (cm) and leaf area index of field-pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Plant height (cm)				Leaf area index			
	150 DAS	180 DAS	210 DAS	At harvest	150 DAS	180 DAS	210 DAS	At harvest
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	35.6	98.7	19.3	19.7	2.28	3.43	4.47	2.32
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	38.2	101.0	19.4	19.8	2.29	3.51	4.93	2.69
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	43.4	103.8	19.7	20.3	2.32	3.58	5.00	2.75
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	43.6	104.2	19.8	20.3	2.34	3.61	5.14	2.81
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	43.8	104.7	19.8	20.4	2.34	3.66	5.28	2.89
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	26.8	75.7	16.3	16.8	2.05	2.96	4.48	2.32
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	28.8	77.0	16.6	17.1	2.10	3.22	4.94	2.71
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	31.4	78.6	16.7	17.2	2.07	3.27	5.01	2.75
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	32.3	80.3	17.0	17.5	2.12	3.36	5.09	2.77
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	32.4	81.1	17.1	17.6	2.14	3.49	5.10	2.77
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	42.1	103.3	19.5	20.1	2.32	3.42	4.94	2.73
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	32.6	84.3	17.9	18.4	2.11	3.18	4.47	2.35
Hand weeding (continuously at 20 days interval from Mid-February)	46.1	108.3	20.1	20.6	2.48	3.83	5.91	3.47
Weedy check	22.3	65.8	15.0	15.8	1.99	2.62	4.07	2.00
LSD (p=0.05)	6.9	28.9	1.1	1.0	0.06	0.08	0.06	0.26

*DAS= Days after sowing; PE= pre-emergence application; PoE=post-emergence application; *fb*= followed by

Table 2. Dry matter accumulation (g/plant) and mean crop growth rate (g/m^2/day) of field-pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Dry matter accumulation (g/plant)				Mean crop growth rate (g/m^2/day)			
	150 DAS	180 DAS	210 DAS	At harvest	150 DAS	180 DAS	210 DAS	At harvest
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	2.88	5.26	6.95	7.44	2.92	4.64	4.79	2.76
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	3.09	5.84	7.80	8.53	3.14	5.22	5.45	3.61
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	3.31	6.28	8.65	9.46	3.38	5.62	6.28	4.00
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	3.33	6.39	8.77	9.50	3.39	5.74	6.34	3.84
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	3.37	6.46	8.82	9.53	3.43	5.80	6.33	3.80
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	2.29	4.31	6.02	6.30	2.37	3.85	4.43	1.74
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	2.34	4.45	6.24	6.58	2.41	3.99	4.60	2.14
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	2.39	4.92	7.06	7.31	2.45	4.54	5.34	1.97
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	2.42	5.10	7.45	7.82	2.48	4.73	5.72	2.50
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	2.43	5.32	7.76	8.12	2.49	4.99	5.95	2.43
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	3.23	6.20	8.54	9.11	3.30	5.57	6.19	3.30
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	2.29	4.86	6.80	7.30	2.38	4.52	5.01	2.80
Hand weeding (continuously at 20 days interval from Mid-February)	3.63	6.55	9.04	9.66	3.64	5.73	6.56	3.60
Weedy check	2.15	4.04	5.56	5.79	2.14	3.60	16.18	1.69
LSD (p=0.05)	0.08	0.08	0.07	0.07	0.09	0.08	0.34	0.27

*DAS= Days after sowing; PE= pre-emergence application; PoE=post-emergence application; *fb*= followed by

0.125 kg/ha PoE were found either at par or next to the hand weeding treatment during both the years. These results indicated that the sequential application of pendimethalin 1.00 kg/ha PE and imazethapyr 0.100 and 0.125 kg/ha PoE significantly minimized crop-weed competition and promoted plant growth in an effective and efficient manner. The observed enhancement in crop growth with increasing doses of post emergence application of imazethapyr is primarily attributable to lower density and dry matter of weeds which might have created congenial environment for crop growth and development which led to more accumulation of dry matter per plant. The weedy check treatment resulted in reduced dry matter accumulation due to increased weed growth, leading to intense competition for essential growth factors. Similar findings were also reported by Rana *et al*. (2013) and Sultana *et al*. (2009).

Crop growth analysis

Mean field-pea crop growth rate (CGR) (g/m^2/ day) which indicates growth rate of the crop based on dry matter accumulation (DMA) per unit ground area over a period. From 120-150 DAS and 180-210 DAS, higher values of mean CGR were observed with hand weeding treatment which were at par with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 and 0.125 kg/ ha PoE (**Table 3)** Mean relative growth rate (RGR) (mg/g/day) indicates growth rate based on increase in dry matter over initial dry matter produced. Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE were either at par or were the next best treatments after hand weeding (**Table 3)** Mean net assimilation rate (NAR) (g/m^2/day) indicated net dry matter accumulation depending on total leaf areas produced at various growth stages. Hand weeding treatment recorded highest NAR followed by pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE (**Table 3**). Mean RGR and mean NAR declines as the crop proceeds towards maturity as leaves advance towards senescence. Thus, leaf area decreases at the later stage consequently rate of dry matter production diminishes. This indicates that any weed management practice that decreases the crop-weed competition sets higher growth rate of crop. Due to effective control of weeds, reduced crop-weed competition resulted in better growth and development of crop as reported by Rana *et al*. (2015).

Field pea yield attributes and yield

The field pea yield attributes indicate final output of total growth and development of a crop (**Table 4**). During both the years, hand weeding treatment recorded significantly higher number of pods/ plant, number of seeds/pod and seed index over herbicidal treatments. However, all the herbicidal treatments were significantly superior over weedy check during both the years. Among the herbicidal treatments application of pendimethalin 1.00 kg/ha PE *fb* manual weeding twice and pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 and 0.125 kg/ha PoE recorded significantly highest number of pods/plant, number of seeds/pod and seed index during both the years. Higher yield attributes with herbicidal treatments might be due to lesser crop weed competition.

During both the years, higher biological yield of field pea was recorded with hand weeding treatment (**Table 4**). Among the herbicidal treatments, higher

Table 3. Mean relative growth rate (mg/g/day) and net assimilation rate (g/m^2/day) of field pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Mean relative growth rate (mg/g/day)				Mean net assimilation rate (g/m^2/day)			
	120-150 DAS	150-180 DAS	180-210 DAS	At harvest	120-150 DAS	150-180 DAS	180-210 DAS	At harvest
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	16.15	11.00	7.48	3.66	4.61	2.85	2.35	5.74
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	16.45	11.32	7.62	4.22	5.35	3.16	2.59	6.09
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	16.59	11.32	8.04	4.21	5.98	3.33	2.92	6.43
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	16.40	11.42	7.98	3.99	5.98	3.38	2.92	6.44
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	16.37	11.44	7.89	3.93	6.09	3.40	2.87	6.40
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	17.98	11.27	8.17	2.74	4.41	2.67	2.32	4.25
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	17.37	11.35	8.19	3.21	4.43	2.62	2.26	4.43
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	17.20	12.05	8.50	2.59	4.58	2.97	2.60	4.81
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	17.12	12.21	8.70	3.16	4.49	3.01	2.73	4.89
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	16.98	12.50	8.72	2.91	4.48	3.10	2.80	4.79
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	16.77	11.43	8.00	3.56	5.67	3.41	2.95	6.04
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	18.40	12.32	8.19	3.78	4.49	3.01	2.54	5.05
Hand weeding (continuously at 20 days interval from Mid-February)	15.27	10.88	8.02	3.66	6.22	3.20	2.83	6.35
Weedy check	14.77	11.25	7.97	2.85	3.17	2.72	2.28	4.01
LSD (p=0.05)	NS	NS	NS	0.39	0.40	0.08	0.07	0.52

*DAS= Days after sowing; PE= pre-emergence application; PoE=post-emergence application; *fb= followed by*

biological yield was recorded with pendimethalin 1.00 kg/ ha PE *fb* imazethapyr 0.125 kg/ha PoE which were at par pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 and 0.100 kg/ha PoE. Seed yield during both the years also followed the same trend but pendimethalin 1.0 kg/h PE *fb* imazethapyr 0.125 kg/ha PoE was at par with pendimethalin 1.0 kg/ha PE *fb* imazethapyr 0.075 and 0.100 kg/ha PoE and followed by manual weeding. Stover yield was also higher with hand weeding treatment during both the years. The minimum biological, seed and stover yield of field pea was observed with weedy check treatment during both the years due to more weed infestation which resulted in poor crop growth and poor development of yield attributing characters. Similar findings have been reported by Bhyan *et al.* (2004) and Rajeev *et al.* (2006).

Economics

Pendimethalin 1.0 kg/ha PE *fb* imazethapyr 0.125 kg /ha PoE recorded the highest B:C of 2.66 and 3.01 during the first and second year, respectively followed by pendimethalin 1.0 kg/ha PE *fb* imazethapyr 0.100 and 0.075 kg/ha PoE. This could be primarily due to superior weed control at low cost and increased yield. Similar findings were noted by Singh (2011) and Kumar *et al.* (2010).

Effect on weeds

Weed biomass: The predominant weed species infesting the field pea crop at 150 DAS and 175 DAS were *Lolium perenne, Ranunculus arvensis, Caposella bursa pastoris, Stellaria media, Fumaria parviflora, Angelis arvensis* and *Matric aria chamomilla*. Weed biomass was significantly lower with the hand weeding treatment during both the years (**Table 5**). Among herbicidal treatments at 150 DAS during both the years, pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075, 0.100 and 0.125 kg/ha PoE significantly reduced weed biomass which were next to hand weeding treatment. At 175 DAS during both the years, application of pendimethalin 1.00 kg/ha PE or oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice reduced the weed biomass which were followed by pendimethalin 1.00 kg/ ha PE *fb* imazethapyr 0.100 and 0.125 kg/ha PoE. None of the treatments were comparable to hand weeding treatment in controlling weeds. However, all the herbicide treatments were significantly superior to weedy check treatment. It might be because the manual weeding consistently exhibits lower weed biomass compared to herbicide treatments. Besides, effective weed control by manual weeding, the main reason of reducing weed biomass under sequential application of herbicides was because of first flush of weeds was controlled by pendimethalin PE and the second flush of weeds were controlled by imazethapyr PoE due to its broad-spectrum properties. Also, dense crop canopy at later stages might have suppressed weed growth and ultimately reduced dry weight. Similar findings were also reported by Kumar *et al*. (2002), Buttar *et al*. (2008) and Mathukia *et al*. (2015).

Weed control index (WCI): During both the years at 150 DAS and at 175 DAS, the mean WCI of 83.52% and 95.61% was recorded with hand weeding (**Table 5**). Among the herbicidal treatments, at 150 DAS, the highest mean WCI was recorded with pendimethalin

Table 4. Yield attributing parameters and yield parameters of field pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Yield attributing parameters			Biological yield (t/ha)		Seed yield (t/ha)		Stover yield (t/ha)		B:C	
	No. of pods/plant	No. of seeds/ pod	Seed index (g)	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	20.3	5.18	16.38	5.86	6.47	1.09	1.51	4.77	4.96	1.43	1.91
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	20.5	5.30	16.62	7.72	8.45	1.32	1.92	6.39	6.54	1.73	2.41
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	20.8	5.33	18.28	9.81	10.07	1.98	2.35	7.83	7.72	2.55	2.94
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	20.9	5.37	18.33	9.88	10.18	2.03	2.37	7.85	7.81	2.59	2.94
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	21.0	5.42	18.42	9.96	10.24	2.10	2.45	7.85	7.79	2.66	3.01
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	20.2	5.05	15.67	4.22	4.59	1.03	1.44	3.19	3.15	1.35	1.83
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	20.3	5.10	16.19	4.60	5.04	1.16	1.52	3.44	3.53	1.46	1.86
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	20.4	5.13	17.09	5.54	6.36	1.47	1.75	4.06	4.61	1.84	2.14
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	20.5	5.17	17.62	6.56	7.04	1.54	2.00	5.02	5.03	1.93	2.43
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	21.0	5.22	17.87	7.31	7.35	1.72	2.07	5.59	5.29	2.14	2.49
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	21.4	5.47	18.35	9.18	9.25	1.99	2.36	7.19	6.90	1.98	2.31
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	20.5	5.33	15.47	5.86	5.99	1.53	1.77	4.33	4.23	1.51	1.67
Hand weeding (continuously at 20 days interval from Mid-February)	24.7	6.09	19.74	10.33	10.66	2.47	2.76	7.86	7.90	2.24	2.46
Weedy check	16.2	3.62	14.74	3.78	3.90	0.89	1.06	2.88	2.84	1.26	1.47
LSD (p=0.05)	0.50	0.13	0.30	0.55	0.31	0.24	0.19	0.67	0.36		

*PE= pre-emergence application; PoE=post-emergence application; *fb= followed by*

Table 5. Weed biomass (g/m^2), weed control index (%) and weed index (%) of field pea as influenced by treatments (pooled 2021-22 and 2022-23)

Treatment	Weed biomass (g/m^2)		Weed control index (%)		Weed index (%)
	150 DAS	175 DAS	150 DAS	175 DAS	
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	2.85	3.99	69.38	46.06	50.3
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	2.82	3.82	70.35	54.69	38.3
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	2.56	3.46	80.28	69.66	16.9
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	2.55	3.46	80.53	69.83	15.2
Pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	2.54	3.45	80.94	70.02	12.4
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.025 kg/ha PoE	2.76	3.80	72.84	55.79	52.8
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.050 kg/ha PoE	2.74	3.78	73.78	56.51	48.7
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE	2.74	3.78	73.78	56.79	38.0
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.100 kg/ha PoE	2.72	3.76	74.29	57.83	32.1
Oxyfluorfen 0.150 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE	2.72	3.76	74.50	57.80	27.2
Pendimethalin 1.00 kg/ha PE *fb* manual weeding twice	2.75	2.61	73.36	90.84	17.1
Oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice	2.63	2.45	77.69	93.22	36.6
Hand weeding (continuously at 20 days interval from Mid-February)	2.44	2.23	83.52	95.61	0.0
Weedy check	3.81	4.65	0.00	0.00	62.4
LSD (p=0.05)	0.04	0.05			

*DAS= Days after sowing; PE= pre-emergence application; PoE=post-emergence application; *fb= followed by*

1.00 kg/ha PE *fb* imazethapyr 0.125, 0.100 and 0.075 kg/ha PoE with mean WCI of 85.5, 85.0 and 83.5% respectively. Also at 175 DAS, pendimethalin 1.00 kg/ha PE or oxyfluorfen 0.150 kg/ha PE *fb* manual weeding twice recorded highest mean WCI with mean WCI of 93.2 and 90.8% respectively which was further followed by pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125, 0.100 and 0.075 kg/ha PoE with mean WCI of 70.0, 69.8 and 69.7% respectively. The hand weeding treatment underscores the importance of maintaining weed free environment for maximizing crop productivity (Brown and Green 2024). The reason for the highest WCI can be attributed to its effective control of all types of weeds as reported by Rana *et al*. (2004).

Weed index (WI): The lowest weed biomass was recorded under hand weeding treatment resulted in lowest weed index (0.00%) during both the years (**Table 5**). Among the herbicidal treatments, lowest mean weed index was observed in pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 and 0.100 kg/ha PoE with mean WI of 12 and 15% respectively. It was 17% with pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.075 kg/ha PoE and manual weeding twice. Maximum mean WI was observed with weedy check treatment of 62.4%. Similar findings were also reported by Kumar and Singh (2014) and Johnson and Holm (2010).

Conclusion

It can be concluded that pendimethalin 1.00 kg/ha PE *fb* imazethapyr 0.125 kg/ha PoE was the most cost-effective treatment to manage weeds and realizing higher seed yield in field pea.

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