International Journal of Plant & Soil Science

Volume 35, Issue 23, Page 316-327, 2023; Article no.IJPSS.110775
ISSN: 2320-7035

Evaluation of Herbicides for the Management of Complex Weed Flora in French Bean (*Phaseolus vulgaris* L.) under Mid Hill Conditions of Himachal Pradesh, India

Ketan [a], Sunil Kumar Gola [b*], Shabnam Thakur [c], S. S. Rana [c], D. R. Chaudhary [a], Sumit Kumar [b] and Priyanshi kaul [a]

[a] Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur 176062, HP, India.
[b] Department of Vegetable Science, CCS Haryana Agricultural University, Hisar 125004, India.
[c] Department of Agronomy, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur 176062, HP, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2023/v35i234246

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/110775

Original Research Article

Received: 13/10/2023
Accepted: 19/12/2023
Published: 21/12/2023

ABSTRACT

A field experiment was conducted at Experimental Farm of the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur during *Kharif*, 2022 to study the effect of herbicide combinations for the management weeds in French bean (*Phaseolus vulgaris* L.). The experiment

**Corresponding author: E-mail: sprajapatkhirbi@gmail.com;*

was laid out in Randomized Block Design with three replications and comprised of eleven weed control treatments *viz.,* oxyfluorfen 150 g ha^{-1} (pre-emergence), pretilachlor 1000 g ha^{-1} (pre-emergence), imazethapyr 100 g ha^{-1} (pre-emergence), quizalofop- ethyl 100 g ha^{-1} (pre-emergence), oxyfluorfen 100 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1} (post-emergence), pretilachlor 700 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1} (post-emergence), imazethapyr 70 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1} (post-emergence), pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 50 g ha^{-1}+ chlorimuron 3 g ha^{-1} (post-emergence), pretilachlor 500 g ha^{-1}+ imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW, 2 HWs (30 and 45 DAS) and weedy check. Results of the study revealed that hand weeding (twice) and pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW effectively reduced weed count and dry matter of the weed species. Highest weed control efficiency of 75.6 per cent was obtained from hand weeding (twice) treatment followed by 63.7 per cent with pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW. The treatment, hand weeding (twice) also produced significantly higher pod yield (16.14 t/ha), gross (₹ 2, 83,795) and net (₹2, 66,732) returns due to weed control. Amongst herbicidal treatments, pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW proved best as it resulted in significantly higher pod yield (14.24 t/ha), gross (₹ 2, 38,006) and net (₹ 2, 31,129) returns due to weed control. The treatment, Imazethapyr 100 g ha^{-1} gave the highest marginal benefit cost ratio (MBCR) of 178.9.

Keywords: French bean; imazethapyr; quizalofop-ethyl; oxyfluorfen; pretilachlor; weed flora.

1. INTRODUCTION

French bean (*Phaseolus vulgaris* L.), being the monopoly of hill farmers [1,2], is commercially cultivated in an area of about 228.0 thousand hectares with a production of 2257 thousand metric tons in the country. “In Himachal Pradesh, it is mainly cultivated as a market crop in mid and high hill areas, covering 3.82 thousand hectares with a production of about 50.87 thousand metric tons. Its cultivation has become more popular amongst growers on account of its off-seasonality, relative ease in cultivation and highest profit margins. Of the various reasons for its low productivity, weeds pose the serious threat on account of frequent irrigation and high fertility which provide conducive environment for their growth and development and consequently reduce yield by 20-60 per cent” [3]. “Though, the weeds can be effectively managed with the application of pre-emergence herbicides at critical period of crop weed competition but the continuous application of pre-emergence herbicides in crops alters annual-perennial balance in favour of perennial weeds” [4]. “Use of pre-emergence herbicides at low doses in conjunction with manual weeding 30-40 days after seeding is environmentally safe, socially acceptable and economically viable” [5]. “However, unavailability of labour at critical period of crop-weed competition and sometimes unfavourable field conditions do not permit manual weeding. In literature, sufficient information on pre-emergence herbicides to control weeds has been reported from various quarters but the information on post-emergence herbicides or their combinations is lacking. Many a times, extension workers and farmers demand information on post-emergence herbicides or their combinations particularly when they fail to spray pre-emergence herbicides due to one or other reasons and paucity of labour for manual weeding. Hence, it becomes imperative to identify appropriate herbicide (s) and their combinations to manage the complex weed flora in French bean” [6].

“Weeds have been recognized as a serious problem ever since the man started domesticating/cultivating plants and since then the battle against weeds is ever ending and often the costliest agronomic input for successful crop production. Weeds are the most under estimated crop pests in agriculture and cause maximum reduction in crop yields than other pest and diseases. Of the total annual loss of agricultural produce from various pests in India, weeds roughly account for 37%, insects for 29%, diseases for 22% and other pests for 12%” [7]. “Weeds are the silent robbers of plant nutrients, moisture, sunlight and compete for space that would otherwise be available to main crop. Weeds also harbour pests and disease causing organisms, cause adverse allelopathic effects on crop and reduce the yield and quality of the produce” [6].

“Weeds cause approximately 9.5% yield loss of wheat globally” [8]. “Phalaris minor, Avena fatua,

Chenopodium album, Lathyrus aphaca, Angalis arvensis, and Melilotus indica are the most common and troublesome ones" [9,8]. "Since weeds possess competitive and deleterious effects on each growth phase of wheat, it is of prime importance to follow new systems for their management" [10].

"The wide usage of herbicides increases the chances of weed resistance and farmer's dependence. In addition to the resistance, the hazard caused by herbicides and their persistent toxic effect on the quality of all life aspects after reaching the action site are other major issues related to the chemical control" [11,12]. "Despite those several herbicide side effects, its use is extremely important in augmenting crop productivity to face all the necessities of food security and sustainability of human populations" [13].

"Manual method of weed control is labour intensive, cumbersome and time consuming whereas, the mechanical methods of weed control are reported to cause injury to the root system. Weeds can be effectively controlled by manual, mechanical and chemical methods. Unavailability of labour at critical period of crop-weed competition and sometimes unfavorable field conditions do not permit manual weeding. Under such situations, use of herbicides becomes imperative. However, use of herbicides at low doses in conjunction with manual weeding is environmentally safe, socially acceptable and economically viable" [5]. Herbicides like fluchloralin as pre-plant-incorporation (PPI) and pendimethalin as pre-emergence (PE) have been recommended for weed control but these are effective only during initial period of crop growth (up to 30 DAS). Thus, for the effective control of weeds throughout the crop season, use of post-emergence herbicides or their combinations is necessary. There is every possibility that use of single post-emergence herbicide coupled with pre-emergence herbicide may prove effective and raise the income of farmers.

2. MATERIALS AND METHODS

The field investigation was carried out at Experimental Farm of the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur [32˚6´ North latitude and 76˚3´ East longitude and 1290 m above mean sea level] during *kharif*, 2022. The site is falling under mid-hill zone of Himachal Pradesh. The soil of this zone is of podzolic type with pH range of 5.0-6.0. Soil of experimental field was silty clay loam in texture, acidic in reaction, medium in organic carbon (0.71%), medium in available nitrogen (407 kg/ha), phosphorus (17.2 kg/ha) and potassium (162 kg/ha). Eleven treatment combinations namely, oxyfluorfen 150 g/ha (pre-emergence), pretilachlor 1000 g/ha (pre-emergence), imazethapyr 100 g/ha (pre-emergence), quizalofop- ethyl 100 g ha^{-1} (pre-emergence), oxyfluorfen 100 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1} (post-emergence), pretilachlor 700 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1} (post-emergence), imazethapyr 70 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1} (post-emergence), pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 50 g ha^{-1} + chlorimuron 3 g ha^{-1} (post-emergence), pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW, 2 HWs (30 and 45 DAS) and weedy check were evaluated in a randomized block design with three replications. "Herbicidal sprays as per treatments were applied immediately after sowing (pre-emergence) and 30 days after sowing (post-emergence) with the help of knapsack sprayer using flat fan nozzle in 750 liters of water per hectare. Weed count and weed dry weight were recorded at 40, 60 days after sowing (DAS) and at harvest. Growth, yield attributes and yield were recorded at different growth and harvest times. The data were subjected to statistical analysis as per Panse and Sukhatme [14] and the treatments were compared at 5 per cent level of significance to interpret the differences. The weed count data were analyzed after subjecting the original data to square root transformation *i.e.* $\sqrt{(x+0.5)}$ and the treatment effects were compared using transformed means" [6]. Weed control efficiency of different treatments was calculated as per the following formula given by Mishra and Tosh [15].

$$\text{Weed control efficiency (\%)} = \frac{\text{DWC} - \text{DWT}}{\text{DWC}} \times 100$$

Where,
DWC - weed dry weight (g/m^2) in control plot, and
DWT - weed dry weight (g/m^2) in treated plot

3. RESULTS AND DISCUSSION

The dominant weed flora of the experiment site was comprised of *Digitaria sanguinalis, Trifolium repens, Artimissia vulgaris, Cyperus rotundus* and *Alternanthera philoxeroides.* A similar type of weed flora in French bean has also been

reported by Rana et al. [16] under the mid-hill conditions of Himachal Pradesh.

3.1 Total Weed Count

Weed control treatments had significantly influenced the population of total weeds at all the stages of observation (Table 1). Significantly highest count of total weeds was observed in weedy check. All the weed control treatments significantly reduced the population of total weeds over weedy check at all the stages of the observation. Hand weeding (twice) had the lowest population of total weeds at all the stages of observation.

Application of pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW resulted in significantly lower population of total weeds at all the stages of observation but it was at par with pretilachlor 1000 g ha^{-1} (pre-emergence) at 80 DAS. This was due to effective control of the weeds with the spray of pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW which reduced the species-wise weed population and ultimately resulted in lowest weed count. The treatment, oxyfluorfen 100 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1} (post-emergence) was found to be least effective against total weed population at all the stages of observation.

3.2 Total Weed Dry Weight

The effects of weed control treatments on total weed dry matter accumulation have been presented in Table 2. There was gradual increase in total weed dry matter accumulation from 40 DAS up to harvest (80 DAS) in all weed control treatments. Weed control treatments had significantly influenced the dry matter accumulation of total weeds at all the stages of observation. Significantly higher total weed dry matter accumulation was recorded in weedy check at all the stages of observation. All the weed control treatments showed significant reduction in total weed dry matter accumulation over weedy check at all the stages of observation.

Table 1. Effect of weed control treatments on total weed count (No./m^2) at different stages of observation in French bean

Treatment	Dose (g/ha)	40 DAS	60 DAS	At harvest
Oxyfluorfen	150	13.1 (170.7)	13.4 (180.0)	15.7 (245.3)
Pretilachlor	1000	11.4 (130.7)	11.8 (138.7)	14.8 (220.0)
Imazethapyr	100	14.1 (197.3)	14.1 (198.7)	17.0 (289.3)
Quizalofop-ethyl	100	14.7 (216.0)	15.5 (238.7)	17.8 (316.0)
Oxyfluorfen *fb* quizalofop-ethyl	100 *fb* 70	16.3 (265.3)	15.8 (249.3)	18.6 (344.0)
Pretilachlor *fb* quizalofop-ethyl	700 *fb* 70	15.3 (234.7)	14.1 (197.3)	16.9 (284.0)
Imazethapyr *fb* quizalofop-ethyl	70 *fb* 70	15.4 (236.0)	15.1 (226.7)	18.1 (326.7)
Pretilachlor+ imazethapyr *fb* quizalofop-ethyl+ chlorimuron ethyl	500 + 50 *fb* 50 + 3	15.1 (226.7)	14.1 (200.0)	17.2 (294.7)
Pretilachlor + imazethapyr *fb* HW	500 + 50	9.1 (82.7)	10.0 (100.0)	14.3 (204.0)
Hand weeding (twice)	-	1.2 (1.3)	7.2 (52.0)	12.0 (144.0)
Weedy check	-	19.3 (373.3)	21.1 (445.3)	24.0 (576.0)
SE (m)±		0.3	0.4	0.3
CD (P = 0.05)		1.0	1.3	1.0

Values given in the parentheses are the mean of original values, Data subjected to ($\sqrt{(x+0.5)}$) square root transformation; DAS: days after sowing, PE: pre-emergence, PoE: post-emergence, HW: hand weeding and fb: followed by

Table 2. Effect of weed control treatments on dry weight of weeds (g/m^2) and weed control efficiency at different stages of observation

Treatment	Dose (g/ha)	40 DAS	60 DAS	At harvest
Oxyfluorfen	150	2.2 (4.7)	7.1 (49.3)	8.7 (74.7)
Pretilachlor	1000	1.8 (2.7)	5.8 (33.3)	7.5 (56.0)
Imazethapyr	100	2.1 (4.0)	5.8 (33.3)	7.8 (61.3)
Quizalofop-ethyl	100	1.9 (3.1)	5.7 (32.0)	7.4 (54.7)
Oxyfluorfen *fb* quizalofop-ethyl	100 *fb* 70	2.6 (6.1)	6.0 (36.0)	9.8 (96.0)
Pretilachlor *fb* quizalofop-ethyl	700 *fb* 70	2.4 (5.9)	7.9 (61.3)	8.3 (68.0)
Imazethapyr *fb* quizalofop-ethyl	70 *fb* 70	2.3 (5.1)	6.9 (46.7)	8.3 (69.3)
Pretilachlor+ imazethapyr *fb* quizalofop-ethyl+ chlorimuron ethyl	500 + 50 *fb* 50 + 3	2.1 (3.8)	5.7 (32.0)	8.3 (68.0)
Pretilachlor + imazethapyr *fb* HW	500 + 50	1.5 (1.8)	5.3 (28.0)	7.3 (53.3)
Hand weeding (twice)	-	0.7 (0.0)	4.0 (16.0)	5.6 (30.7)
Weedy check	-	3.1 (9.2)	9.3 (85.3)	10.3 (106.7)
SE (m)±		0.3	0.3	0.4
CD (P = 0.05)		0.8	0.7	1.1

Values given in the parentheses are the mean of original values, Data subjected to ($\sqrt{(x+0.5)}$) square root transformation; DAS: days after sowing, PE: pre-emergence, PoE: post-emergence, HW: hand weeding and fb: followed by

Table 3. Effect of weed control treatments on dry weight of weeds (g/m^2) and weed control efficiency at different stages of observation

Treatment	Dose (g/ha)	Weed control efficiency (%)
Oxyfluorfen	150	46.2
Pretilachlor	1000	59.3
Imazethapyr	100	54.7
Quizalofop-ethyl	100	52.8
Oxyfluorfen*fb* quizalofop-ethyl	100 *fb* 70	49.7
Pretilachlor *fb* quizalofop-ethyl	700 *fb* 70	52.3
Imazethapyr *fb*quizalofop-ethyl	70 *fb* 70	49.9
Pretilachlor+ imazethapyr *fb*quizalofop-ethyl+ chlorimuron ethyl	500 + 50 *fb* 50 + 3	56.8
Pretilachlor + imazethapyr *fb* HW	500 + 50	63.7
Hand weeding (twice)	-	75.6
Weedy check	-	-

Among the treatments, hand weeding (twice) had significantly lower total weed dry matter accumulation as compared to other treatments. Among various herbicidal treatments, pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW behaving statistically alike with quizalopfop-ethyl 100 g ha^{-1} (post-emergence), pretilachlor 1000 g ha^{-1} (pre-emergence), imazethapyr 100 g ha^{-1} (pre-emergence) and pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 50 g ha^{-1} + chlorimuron ethyl 3 g ha^{-1} (post-emergence) resulted in lowest dry matter accumulation of total weeds at all the stages on account of effective control of the weeds with the application of pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW which significantly reduced the species-wise weed count and ultimately resulted in lowering the weed dry matter accumulation.

3.3 Weed Control Efficiency

The data on effect of different treatments on weed control efficiency have been presented in Table 3. Hand weeding (twice) resulted in highest weed control efficiency of 75.6 per cent.

However, amongst different herbicidal treatments, pretilachlor 500 g/ha + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW had the highest weed control efficiency of 63.7 per cent which was followed by pretilachlor 1000 g ha^{-1} (pre-emergence) and pretilachlor 500 g g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 50 g ha^{-1} + chlorimuron ethyl 3 g/ha (post-emergence) which displayed 59.3 and 56.8 per cent weed control efficiencies, respectively. However, the lowest weed control efficiency of 46.2% was recorded in oxyfluorfen 150 g ha^{-1} (pre-emergence). The results are in confirmation with the findings of Kavad et al. [17], Singh et al. [18], Gupta et al. [19], Patel et al. [20], Ram et al. [21], Prachand et al. [22], Bali et al. [23], Rana et al. [21], Devi et al. [24] and Devaraju and Senthivel [25] who observed the highest weed control efficiencies and lowest weed dry weight in their experimental studies.

3.4 Effect on Crop

3.4.1 Dry matter accumulation (g/m^2)

Dry matter accumulation of plants as influenced by different weed control treatments has been presented in Table 4. A critical analysis of the values in the table indicated that dry matter accumulation (g/m^2) of the plants was drastically influenced by different weed control treatments. Hand weeding (twice) had significantly highest dry matter accumulation (g/m^2) of plants but behaved statistically similar with the herbicidal treatment, pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW. Amongst weed control treatments, pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW had the highest dry matter accumulation (g/m^2) when evaluated against other herbicidal treatments. The next best treatment was pretilachlor 1000 g ha^{-1} (pre-emergence), which was statistically different from pretilachlor 500 g ha^{-1} + imazethapyr 50 g/ha (pre-emergence) *fb* HW and hand weeding (twice). The treatment, oxyfluorfen 150 g/ha (pre-emergence) had lowest dry matter accumulation (g/m^2) which was comparable with oxyfluorfen 100 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 70 g ha^{-1} (post-emergence), pretilachlor 700 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 70 g ha^{-1} (post-emergence) and imazethapyr 70 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 70 g ha^{-1} (post-emergence). The results are in close conformity with the results obtained by Rana et al. [26] in rajmash.

3.4.2 Haulm yield (kg/m^2)

The influence of different weed control treatments on haulm yield has been depicted in Table 4. It was reflected from the analytical values that haulm yield was significantly influenced by different weed control treatments. Though hand weeding (twice) had the highest haulm yield but it was statistically comparable with pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW, pretilachlor 700 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 70 g/ha (post-emergence) and pretilachlor 1000 g ha^{-1} (pre-emergence). However, the lowest haulm yield of 3.4 kg/m^2area was recorded in the treatment supplemented with the pre-emergence spray of oxyfluorfen 150 g ha^{-1}. The results are in conformity with the findings of Rana et al. [27] who observed the highest halum yield in rajmash supplemented with the two hand weedings.

The effects of treatments on pod yield in tonnes per hectare of French bean have been presented in Table 5. A perusal of data revealed that pod yield (tonnes/ha) was significantly influenced by weed control treatments. Hand weeding (twice) had significantly highest pod yield when compared with other treatments. Among herbicidal treatments, pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW (post-emergence), though at par with hand weeding (twice) had the highestpod yield when compared with other herbicidal treatments. The

next best treatment was pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 50 g ha^{-1} + chlorimuron ethyl 3 g ha^{-1} (post-emergence). The treatment, oxyfluorfen 150 g ha^{-1} (pre-emergence) produced the lowest pod yield as compared to other weed control treatments. This might be due to the effective weed control accomplished with the spray of pre and post-emergence herbicides coupled with hand weedings which produced more number of pods/plant with increased pod weight that ultimately resulted in enhanced pod yield. The results are in confirmation with the findings of earlier researchers Singh et al. [28], Rana et al. [26], Ram et al. [21], Rana et al. [24] in garden pea; Chaudhari et al. [29] in green gram and Gupta et al. [30] in black gram. Uninterupped growth of weeds in the weedy check reduced French bean green pod yield by 66.5% as compared to the best treatment, hand weeding (twice). Green pod yield under the herbicidal treatments was 1.53 to 2.66 times higher than the weedy check treatment.

3.5 Economics

3.5.1 Gross returns

A perusal of data in Table 5 revealed that different weed control treatments increased the gross returns over weedy check. The treatments, hand weeding (twice), pretilachlor 500 g/ha + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW, pretilachlor 1000 g ha^{-1} (pre-emergence), pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 50 g ha^{-1} + chlorimuron ethyl 3 g ha^{-1} (post-emergence), pretilachlor 700 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 70 g ha^{-1} (post-emergence) and imazethapyr 70 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 70 g ha^{-1} (post-emergence) resulted in higher gross returns as compared to rest of the treatments. In general, the spray of herbicides coupled with hand weeding was better than the sole application of herbicides for effective weed management and obtaining higher gross returns [31].

3.5.2 Gross returns due to weed control

Data on gross returns due to weed control of different weed control treatments have been presented in Table 5. The treatment, hand weeding (twice)had highest gross returns of Rs. 283795 per hectare due to weed control followed by pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW (Rs. 238006 per hectare), pretilachlor 1000 g ha^{-1}, pre-emergence (Rs. 175497 per hectare), pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 50 g ha^{-1} + chlorimuron ethyl 3 g ha^{-1} , post-emergence (Rs. 174812 per hectare) and pretilachlor 700 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1}, post-emergence (Rs. 172257 per hectare). However, treatment oxyfluorfen 150 g/ha (pre-emergence) resulted in lowest gross returns of Rs. 76416 per hectare on account of the presence of complex weed flora which comprised of highest weed count and weed dry matter during the entire crop growth stages. This might have resulted in reduced cost of cultivation due to less cost incurred on spray of sole herbicide. The results are in accordance with findings of Shruti and Salankinkop (2015), Patel et al. [20] and Kavad et al. [17].

Table 4. Effect of weed control treatments on dry mater accumulation (g/m^2) and haulm yield (kg/m^2) of plants

Treatment	Dose (g/ha)	Dry matter accumulation (g/m^2)	Haulm yield (kg/m^2)
Oxyfluorfen	150	30.7	3.4
Pretilachlor	1000	41.0	6.3
Imazethapyr	100	35.7	4.8
Quizalofop-ethyl	100	35.3	4.5
Oxyfluorfen*fb* quizalofop-ethyl	100 *fb* 70	33.5	3.8
Pretilachlor *fb* quizalofop-ethyl	700 *fb* 70	33.0	5.7
Imazethapyr *fb*quizalofop-ethyl	70 *fb* 70	32.3	4.8
Pretilachlor+ imazethapyr *fb*quizalofop-ethyl+ chlorimuron ethyl	500 + 50 *fb* 50 + 3	38.0	5.6
Pretilachlor + imazethapyr *fb* HW	500 + 50	46.0	6.8
Hand weeding (Twice)	-	48.0	7.5
Weedy check	-	22.0	2.2
SE (m)±		1.4	0.4
CD (P = 0.05)		4.2	1.1

Table 5. Effect of different weed control treatments on economics of French bean

Treatment	Dose (g/ha)	Pod yield (t/ha)	Cost of cultivation (INR/ha)	Gross returns (INR/ha)	Gross return due to weed control (INR/ha)	Cost of weed control (INR/ha)	Net return due to weed control (INR/ha)	MBCR
Oxyfluorfen	150	7.15	60699	215858	76416	1192	75224	63.1
Pretilachlor	1000	11.39	66913	314939	175497	1732	173765	100.3
Imazethapyr	100	10.31	65099	293374	153932	856	153076	178.9
Quizalofop-ethyl	100	10.68	66317	299634	160192	1528	158664	103.8
Oxyfluorfen *fb* quizalofop-ethyl	100 *fb* 70	9.59	65339	271836	132395	2187	130208	59.5
Pretilachlor *fb* quizalofop-ethyl	700 *fb* 70	11.37	67764	311699	172257	2587	169670	65.6
Imazethapyr *fb* quizalofop-ethyl	70 *fb* 70	11.24	67341	309916	170474	1974	168500	85.3
Pretilachlor + imazethapyr *fb* quizalofop-ethyl + chlorimuron ethyl	500 + 50 *fb* 50 + 3	11.51	67796	314253	174812	2410	172402	71.5
Pretilachlor + imazethapyr *fb* HW	500 + 50	14.24	76134	377447	238006	6876	231129	33.6
Hand weeding (twice)	-	16.14	89168	423237	283795	17063	266732	15.6
Weedy check	-	4.32	54748	139442	0	0	0	0
		9.5						
SE(m) ±		1.3						
CD (P = 0.05)		3.9						

3.5.3 Total cost of cultivation

Data on cost of cultivation of different weed control treatments have been presented in Table 5. The total cost of cultivation (Rs. 89168 per hectare) was recorded higher for hand weeding (twice) on account of the enhancement of wages of the labour deployed for carrying out weeding whereas, minimum cost of Rs. 54748 per hectare was observed under weedy check treatment.

3.5.4 Cost of weed control

Data on cost of weed control of different weed control treatments have been depicted in Table 5. Maximum cost of weed control (Rs. 17063 per hectare) was recorded under hand weeding (twice) treatment due to the deployment of more man power in performing manual weeding. The minimum cost of Rs. 856 per hectare was realized under the treatment, imazethapyr 100 g ha^{-1} (pre-emergence).

3.5.5 Net returns due to weed control

Net returns accrued under different weed control treatments followed almost the same trend as the gross returns. Net returns from hand weeding (twice) treatment were highest (Rs. 266732 per hectare) as compared to other weed control treatments on account of highest gross returns due to weed control (Table 5). This was followed by the combo mixture of pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW, pretilachlor 1000 g ha^{-1} (pre-emergence) and pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 50 g ha^{-1} + chlorimuron ethyl 3 g ha^{-1} (post-emergence). Amongst herbicidal treatment, oxyfluorfen 150 g ha^{-1} (pre-emergence) produced the lowest net returns of Rs. 75224 per hectare due to higher weed count and weed dry matter. The results of the present investigation are in line with the findings of Tewari et al. [32], Ram et al. [21], Chaudhary et al. [33] and Prachand et al. [22] who obtained the highest net returns due to weed control from the herbicidal treatments coupled with hand weeding.

3.5.6 Marginal benefit cost ratio (MBCR)

The data on marginal benefit cost ratio of different weed control treatments have been presented in Table 5. On account of lower cost of weed control and higher net returns due to weed control the treatment, imazethapyr 100 g ha^{-1} (pre-emergence), quizalofop-ethyl 100 g/ha (post-emergence) and pretilachlor 1000 g ha^{-1} (pre-emergence) had the highest marginal benefit cost ratio (MBCR) of 178.9, 103.8 and 100.3 respectively. Contrary to the higher cost of weed control the treatments, hand weeding (twice),pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) *fb* HW, pretilachlor 700 g ha^{-1} (pre-emergence) *fb*quizalofop-ethyl 70 g ha^{-1} (post-emergence), oxyfluorfen 150 g ha^{-1} (pre-emergence) and imazethapyr 70 g ha^{-1} (pre-emergence) *fb* quizalofop-ethyl 70 g ha^{-1} (post-emergence) had the lowest marginal benefit cost ratio (MBCR) of 15.6, 33.6, 59.5, 63.1 and 65.6 respectively, in comparison to other weed control treatments. Similar observations were also recorded by Goud and Dikey, [34], Rana et al. [16], Shekhar et al. [35] in rajmash; Godara and Singh [36] in cluster bean; Prachand et al. [22], Devi et al. [37] in soybean; Tamang et al. [38] in green gram; Ramesh and Radhika [39], Devaraju and Santhivel [40], Gupta et al. [19] and Patel et al. [20] in black gram [41-46].

4. CONCLUSION

The study indicated that weeds in French bean can be controlled effectively with combined application of pretilachlor 500 g ha^{-1} + imazethapyr 50 g ha^{-1} (pre-emergence) fb HW and hand weeding (twice) which further improved the dry matter accumulation, haulm yield and pod yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/110775