Original Research Article

Chemical weed control in field pea [*Pisum sativum*(L.) var arvense]

Abstract

Field pea [*Pisum sativum* (L.) var arvense] is an important pulse crop mainly grown as a winter vegetable in the plains of north India. The effect of ready-mix application along with various pre- and post- emergence herbicides were evaluated for effective and season long weed control in pea. Pre-emergence application of pendimethalin +imazethapyr (ready-mix) at 1250 g ha^{-1} provided excellent control of *Coronopusdidymus*, *Anagallis arvensis* and *Chenopodium album*similar to weed free conditions and resulted in highest yield (1795 kg ha^{-1}) among the herbicidal treatments. Post-emergence (2-4 leaf stage) application of imazethapyr alone and its different ready-mix combinations with imazamox at 60-80 g ha^{-1} provided 86.0-94.0% control of weeds at 60 DAS andresulted the grain yield ranging 1503-1620 kg ha^{-1}.The maximum weed control index at 30 DAS (91.5%) was recorded with pre-emergence application of pendimethalin + imazethapyr at 1250 g ha^{-1} followed by pendimethalin + imazethapyr (PRE) at 1000 g ha^{-1} (87.80%). Pre-emergence application of pendimethalin + imazethapyr (RM) at 1250 g/ha gave the highest net return along with the highest Benefit Cost Ratio (2.36) followed by the same combination at 1000 and 800 g ha^{-1}.

Keywords: Field pea, imazethapyr, imazethapyr +imazamox, ready-mix, weed

1. Introduction

Pulses play an important role to satisfy the growing demands of human food and considered as life-blood of agriculture. In India, where large proportion of population is vegetarian, pulses are an important source of their dietary protein. These have multiple roles in amplifying ecosystem biodiversity as main, cover, catch, green manure, inter crop and provides numerous resource conservation opportunities in the form of healthy and productive soil, prevention of weed emergence, improving nutrient dynamics in favor of soil and plant, in situ water infiltration and conservation (Foyer et al., 2016; Stagnari et al., 2017; Peoples et al., 2019). Among pulses, field pea (*Pisum sativum* L.) is an excellent source of protein (22.5%) with more lysine, tryptophan and carbohydrate (61.5%) and also it contains a range of bioactive compounds such as enzyme inhibitor, phytic acid, lectin, phenolics and oligo-saccharides and thus makes a good supplement for healthy diet due to many health-promoting benefits (Amarakoon et al., 2012). It is grown mainly as a winter vegetable in the plains of north India and occupies 0.62 million hectares area that gives 0.80 million tonnes seed annually with an average productivity of 1292.3 kg ha^{-}

^{1}(FAOSTAT, 2020). India is the largest producer and consumer of pulses in the whole world, having around 25% of the total global production (FAOSTAT, 2020).

The productivity of pea is severely hampered by various biotic and abiotic constraints such as lack of promising varieties, water stress, erratic weather conditions, pest infestations, etc. (Kaur et al., 2020). Among these, weed infestation is the key biotic constraint responsible for lower seed yield as well as poor quality of seed. Pea, because of its slow initial growth rate and short stature, is heavily infested with diverse weed flora, resulting in considerable yield lossesupto65.8% (Mishra, 2006). Moreover, it has relatively a longer critical period of crop-weed competition i.e. 40-60 DAS (Bhyan et al., 2004)due to direct seeded.Also, under weedy conditions, weeds could uptake 49.3 kg ha^{-1} N, 19.7 kgha^{-1} P and 44.7 kg ha^{-1} K, thuscreatingnutrient deficit conditions in pea crop (Mawalia et al., 2017). Further,dominance of broad-leaved weeds in the early stages of crop growth resulted in more competition for soil moisture and nutrients due to their rapid growth and deep root system than pea. Therefore, effective management of weeds is required to reduce losses and improving crop productivity.Manual weeding is generally less preferred by the farmers because this iscumbersome and time-consuming in nature, besides higher wages, (Singh and Wright, 2006). Whereas, mechanical methods mightalso cause injuries to the roots of crop plants (Casarini et al.,1996). So,there is need to evolve weed management practices including herbicides for better management of weeds and higher returns (Vaghasia et al., 2015; Kaur et al., 2020; Miller, 2003).

Among different herbicides, use of pre-emergence herbicides (pendimethalin)is quite common in pea crop (Singh et al., 2008; Singh et al., 2019).Weather variables (rainfall, temperature, sunshine and humidity) and soil moisture considerably influence the bio-efficacy of pre-emergence herbicides (Jursik et al., 2015; Das and Das, 2018). Further, these herbicides are effective only during initial periods of crop growth. Moreover, pre-emergence herbicides showed better efficacy against germinating grassy weeds, while broad-leaved weeds can be better controlled by post-emergence herbicides (Eskin 2000). Therefore, the sole application of pre-emergence herbicides is not adequate to control diverse weed flora during whole crop growth period (Kaur et al., 2020). The sole reliance on herbicides having single mode of action mayalso result in weeds shift and resistance development.Recently few herbicides, particularly imazethapyr and quizalofop ethyl are being used widely for selectively controlling post-emergence weeds in field pea (Kaur et al., 2020; Kumar et al., 2019).Imazethapyr belonging to acetolactate synthase (ALS) inhibitor based mode of action with comparatively more residual period, can be integrated as post emergence with pendimethalin (pre-emergence) for effective and prolong control of weeds in vegetable pea (Kaur et al., 2020). Pendimethalin 1000 g ha^{-1}*fb* imazethapyr +imazamox 60 g ha^{-1} (45 DAS) provided effective control of weeds similar to weed free with reduced NPK uptake by weeds (Mawalia et al., 2017). However, imazamox (0.036-0.045 kg ha^{-1}) applied as post emergence exhibited early season visual toxicity on green pea to the extent of 21-28% (Miller, 2003). Further, these herbicides have been reported to have a long persistence and wide spectrum of weed control (Vaishya et al., 1999). So, the present investigation has been planned to study the efficacy of different herbicides against weeds and their effect on growth andyield of field pea.

2. Materials and methods

2.1. Experimental sites

The field experiments were conducted during the winter seasons 2017-18 at CCS HAU Regional Research Station, Karnal (29º43' N latitude, 76º58' E longitude; altitude 253 m above the mean sea level). The soil of study site was clay loam having pH 7.86, electrical conductivity

0.12 dSm^{-1}, organic carbon 0.40% (Walkley and Black, 1934) with low available N 158 kg ha^{-1} and medium in available P (11.0 kg ha^{-1}) and K (197 kg ha^{-1}) were medium in soil.The climate of Karnal is sub-tropical with mean maximum temperature ranging between 34- 39º C in summer and mean minimum temperature ranging between 6-7º C in winter. Most of the rainfall is received during the months of July to September and few showers during December to late spring. The mean meteorological data recorded for crop season from November, 2017 to March, 2018 depicted in Fig.1 indicate that the mean weekly maximum and minimum temperature fluctuated between 32.4 ºC and 4.1ºC. The mean weekly pan evaporation value varied between 5.5 and 0.8 mmday^{-1} and the total rainfall was 63.2 mm during the crop span. In general, weather conditions were quite favourable for growth of field pea crop.

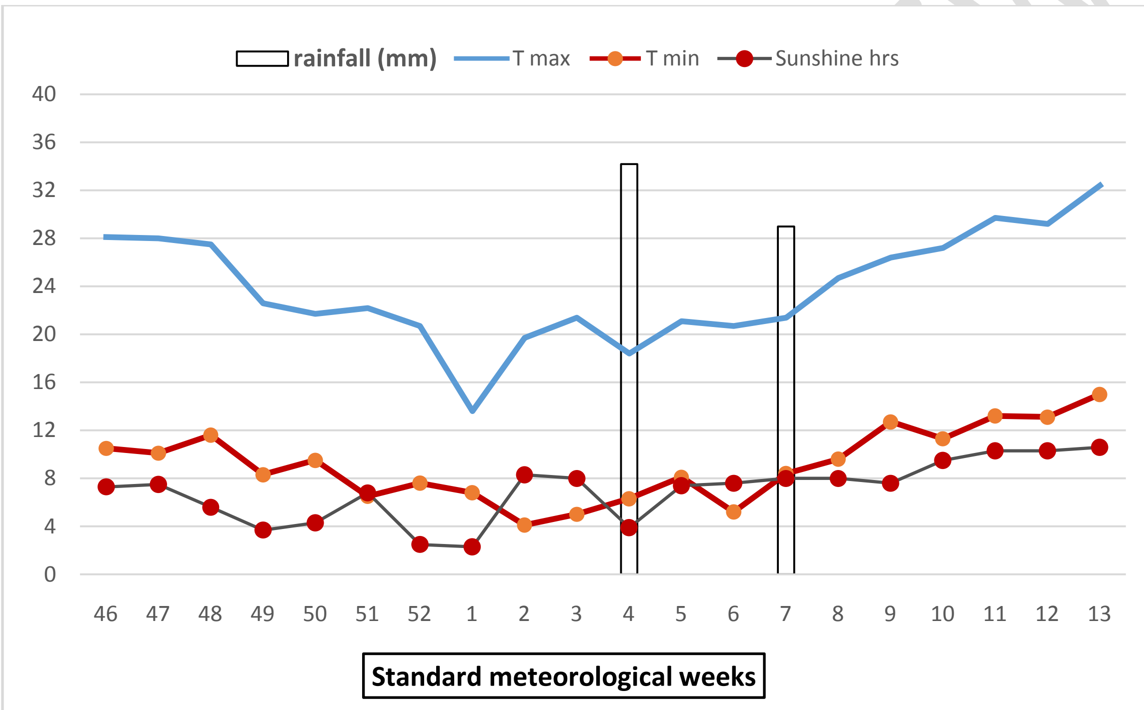

Figure 1: Mean weekly meteorological data from November, 2017 to March, 2018

2.2. Treatment details

Thirteen treatments along with weedy and weed free were laid out in a randomized complete block design with three replications (Table 1). Weeds were removed manually from the weed-free control while, in weedy check plots, weeds were allowed to grow with field pea throughout the growing season. Pea crop was grown during winter after maize in the previous rainy season under the maize - pea sequence.Pendimethalin 30 EC (1000 g ha^{-1}), ready-mix (RM) of pendimethalin + imazethapyr 32 EC (800, 1000 and 1250 g ha^{-1}) and imazethapyr 10 SL (70 g ha^{-1}) were applied as pre-emergence on the next day of sowing,whereasimazethapyr 10 SL (60-80 gha^{-1})and imazethapyr + imazamox 70 WG (60-80 g ha^{-1}) were applied at 2-4 leaf stage as post-emergence.All herbicides were applied with 400 L ha^{-1} water using a knapsack sprayer fitted with a flat fan nozzle.

Table 1: Treatments details

Sr. No.	Treatments	Dose (g ha^{-1})	Time of application
T_1	Clodinafop 15WP	60	35 DAS
T_2	Pinoxaden 5EC	50	35 DAS
T_3	Pendimethalin 30 EC	1000	PRE
T_4	Pendimethalin + imazethapyr 32 EC (RM)	800	PRE
T_5	Pendimethalin + imazethapyr 32 EC (RM)	1000	PRE
T_6	Pendimethalin + imazethapyr 32 EC (RM)	1250	PRE
T_7	Imazethapyr 10 SL	70	PRE
T_8	Imazethapyr 10 SL	60	2-4 leaf stage
T_9	Imazethapyr 10 SL	70	2-4 leaf stage
T_{10}	Imazethapyr 10 SL	80	2-4 leaf stage
T_{11}	Imazethapyr + imazamox 70 WG (RM)	60	2-4 leaf stage
T_{12}	Imazethapyr + imazamox 70 WG (RM)	70	2-4 leaf stage
T_{13}	Imazethapyr + imazamox 70 WG (RM)	80	2-4 leaf stage
T_{14}	Weedy check	-	
T_{15}	Weed free	-	

2.3. Crop management practices

The experimental field was ploughed twice with cultivator after harvest of the previous crop (maize) to crush clods. Stubbles and weeds were removed from the experimental area. Field was ploughed by cross harrowing followed by cultivator twice and planking was done to bring the soil to a fine tilth before sowing. A uniform basal dose of 20 kg nitrogen and 50 kg phosphorus ha^{-1} was applied through DAP at the time of field preparation. The pea crop (variety P-89) was sown at a spacing of 40 cm × 5 cm with seed rate 80 kg ha^{-1}by seed-cum-fertilizer drill on 25 November,2017 and harvested on 23 March, 2018.The recommended package of practices was followed for raising the crop.

2.4. Observations

The number of weeds present in the experimental field was recorded at 30 and 60 DAS. Weeds which were present within two randomly selected (0.5 m x 0.5 m) quadrate in each plot were counted separately, converted to number of weeds per square meter and also subjected to square root transformation before statistical analysis. The samples were oven dried at 70 ℃ till constant weight was achieved. Then dried weed samples were weighed and the weight was expressed in terms of g m^{-2} before subjecting to statistical analysis. Pods picked from randomly selected plants at harvest were counted and finally summed up to arrive at total number of pods per plant. Pods from randomly selected plants were removed carefully by hand. Seeds were separated from straw and then they were counted and an average was worked out. Pods from five randomly selected plants were removed carefully by hand. Seeds were separated from straw and shelling percentage was worked out from harvested pods. The produce of each plot was threshed separately and weighed plot-wise to work out seed yield. Then obtained values were converted into q ha^{-1}.

2.5. Weed indices

Various weed indices were calculated to evaluate bio-efficacy of herbicides treatment in pea as mentioned in Table 2.

Table 2: Different weed indices were calculated as per the following calculations:

Sr. No.	Indices	Calculation
1	Weed control index (WCI) (Mani et al. 1973, Das 2008)	$\frac{\text{Weed weight in control (unweeded)} - \text{Weed weight in a treatment}}{\text{Weed weight in control (unweeded)}} \times 100$
2	Weed index (Gill and Kumar, 1969)	$\frac{\text{Yield from weed free} - \text{Yield of particular treatment}}{\text{Yield of weed free}} \times 100$
3	Herbicide Efficiency index (HEI) (Krishnamurthy et al., 1975)	$\frac{\frac{\text{Yield of treatment} - \text{Yield of control}}{\text{Yield of control}}}{\frac{\text{Weed weight in treatment}}{\text{Weed weight in control}}}$
4	Weed management index (WMI) (Mishra and Mishra, 1997)	$\frac{\text{Percent yield increase over control}}{\text{Percent control of weeds}}$
5	Agronomic management index (AMI) (Mishra and Mishra, 1997)	$\frac{\text{Percent yield increase} - \text{Percent control of weeds}}{\text{Percent control of weeds}}$
6	Integrated weed management index (IWMI) (Mishra and Mishra, 1997)	$\frac{\text{Weed management index (WMI)} + \text{Agronomic management index (AMI)}}{2}$

3. Results and Discussion

3.1. Weed density and dry matter

The major weeds appeared in the experimental field were *Fumaria parviflora*, *Coronopusdidymus*, *Anagallis arvensis* and *Chenopodium album.* Different herbicides showed significant effect on weeds and subsequent crop growth and yield of field pea. The pre-emergence application of imazethapyr at 70 g ha^{-1} and post-emergence application of imazethapyr (70 and 80 g ha^{-1}) at 2-4 leaf stage and its ready mix combinations with pendimethalin at 60-80 g ha^{-1}, reduced the population of *F. parviflora* though up to lesser extent, relative to weedy check (Table 3). The highest density of *F. parviflora* was recorded in weedy check at all the stages. The pre-emergence application of imazethapyr at 70 g ha^{-1}, PRE application of pendimethalin (1000 g ha^{-1}) and its ready mix combinations with imazethapyr at 60-80 g ha^{-1} significantly reduced the population of *C. didymus* over weedy check which was statistically at par with the weed free treatment at all the stages except pendimethalin (PRE) at 1000 g ha^{-1} which was effective only up to 30 DAS. At 60 DAS, post-emergence (2-4 leaf stage) application of imazethapyr and imazethapyr +imazamox (RM) both at 60-80 g ha^{-1} caused significant reduction in weed density. Both at 30 and 60 DAS, among theherbicidal treatments, application of pendimethalin (PRE) at 1000 g ha^{-1}, imazethapyr (PRE)at 70 g $ha^{-1}$and pendimethalin +imazethapyr (RM) applied as pre-emergence at 800-1250 gha^{-1}gave effective control of *A. arvensis*. All the pre-emergence herbicidal treatments gave effective control of *C. album* and caused weed free conditions up to harvest.

Table 3: Effect of weed control treatments on density (No. m^{-2}) of different weeds at different intervals in field pea

Treatment	Dose (g/ha)	Time of application	*Fumaria parviflora* (No.m^{-2})		*Coronopusdidymus*(No.m^{-2})		*Anagallis arvensis* (No.m^{-2})		*Chenopodium album* (No. m^{-2})	
			30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Clodinafop	60	35 DAS	9.96 (98.3)	8.67 (74.3)	4.21 (17.0)	4.82 (22.7)	3.81 (13.7)	4.70 (21.3)	3.02 (8.3)	3.17 (9.3)
Pinoxaden	50	35 DAS	9.95 (98.0)	8.69 (74.7)	4.16 (16.7)	4.97 (24.0)	3.78 (13.7)	4.75 (21.7)	3.10 (8.7)	3.26 (9.7)
Pendimethalin	1000	PRE	9.98 (98.7)	8.01 (63.3)	1.66 (2.0)	4.28 (17.7)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Pendimethalin + imazethapyr (RM)	800	PRE	7.39 (53.7)	6.90 (46.7)	1.00 (0)	1.24 (0.7)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Pendimethalin + imazethapyr (RM)	1000	PRE	7.14 (50.0)	6.79 (45.3)	1.00 (0)	1.24 (0.7)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Pendimethalin + imazethapyr (RM)	1250	PRE	6.99 (48.0)	6.77 (45.0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Imazethapyr	70	PRE	7.15 (50.3)	7.47 (55.0)	1.49 (1.3)	1.41 (1.3)	1.00 (0)	1.49 (1.3)	1.00 (0)	1.00 (0)
Imazethapyr	60	2-4 leaf stage	8.71 (75.0)	7.72 (59.0)	4.10 (16.0)	2.44 (5.0)	3.69 (12.7)	1.99 (3.0)	3.04 (8.3)	2.23 (4.0)
Imazethapyr	70	2-4 leaf stage	7.36 (53.3)	7.48 (55.0)	4.24 (17.0)	2.30 (4.3)	3.59 (12.0)	1.82 (2.3)	2.99 (8.0)	2.14 (3.7)
Imazethapyr	80	2-4 leaf stage	7.48 (55.0)	6.89 (46.7)	4.12 (16.0)	2.23 (4.0)	3.74 (13.0)	1.82 (2.3)	3.09 (8.7)	2.08 (3.3)
Imazethapyr + imazamox (RM)	60	2-4 leaf stage	8.66 (74.0)	7.69 (58.3)	4.31 (17.7)	2.41 (5.0)	3.69 (12.7)	1.90 (2.7)	2.92 (7.7)	1.91 (2.7)
Imazethapyr + imazamox (RM)	70	2-4 leaf stage	8.36 (69.0)	7.65 (57.7)	4.19 (16.7)	1.99 (3.0)	3.64 (12.3)	1.82 (2.3)	2.99 (8.0)	1.72 (2.0)
Imazethapyr + imazamox (RM)	80	2-4 leaf stage	8.32 (68.3)	7.91 (61.7)	4.36 (18.0)	1.90 (2.7)	3.64 (12.3)	1.63 (1.7)	2.99 (8.0)	1.63 (1.7)
Weedy check	-		10.1 (99.3)	8.69 (74.7)	4.36 (18.0)	5.74 (32.7)	3.84 (14.0)	4.72 (21.7)	3.10 (8.7)	3.25 (9.7)
Weed free	-		1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
SE (m) ±			0.21	0.28	0.23	0.30	0.22	0.18	0.17	0.14
CD at 5%			0.59	0.82	0.68	0.87	0.63	0.54	0.50	0.40

Original data given in parenthesis were subjected to square root $\sqrt{(x+1)}$ transformation.

The lowest dry weight of weeds at 30 DAS (1.4 g m^{-2}) was recorded with pre emergenceapplication of pendimethalin +imazethapyr (RM) at 1250 g ha^{-1}*fb* pre emergence application of pendimethalin +imazethapyr (RM) at 1000 g ha^{-1} (2.0 g m^{-2}) and 800 g ha^{-1} (3.1 g m^{-2}), respectively (Table 4). Among the herbicidal treatments, the highest weed dry matter accumulation at all stages was recorded in clodinafop (16.2, 41.8, 145.3 and 99.9 g m^{-2}at 30, 60, 90 DAS and harvest, respectively) and pinoxaden (16.1, 41.8, 144.0 and 99.9 g m^{-2}at 30, 60, 90 DAS and harvest, respectively) both applied at 35 DAS which were found statistically at par with weedy check (16.4, 44.3, 147.6 and 101.9 g m^{-2} at 30, 60, 90 DAS and harvest, respectively). All herbicidal treatments except clodinafop and pinoxaden significantly reduced dry matter accumulation and density of weeds in comparison to weedy check.

Table 4: Effect of weed control treatments on dry matter accumulation (gm^{-2}) by weeds in field pea at different intervals

Treatment	Dose (g ha^{-1})	Time of application	Dry matter accumulation (g m^{-2}) by weed			
			30 DAS	60 DAS	90 DAS	Harvest
Clodinafop	60	35 DAS	4.15 (16.2)	6.54 (41.8)	12.09 (145.3)	10.04 (99.9)
Pinoxaden	50	35 DAS	4.13 (16.1)	6.54 (41.8)	12.04 (144.0)	10.04 (99.9)
Pendimethalin	1000	PRE	2.91 (7.5)	5.43 (28.5)	9.78 (94.6)	8.50 (71.3)
Pendimethalin + imazethapyr (RM)	800	PRE	2.02 (3.1)	3.66 (12.4)	6.73 (44.3)	5.81 (32.8)
Pendimethalin + imazethapyr (RM)	1000	PRE	1.74 (2.0)	3.12 (8.7)	6.06 (35.7)	5.41 (28.3)
Pendimethalin + imazethapyr (RM)	1250	PRE	1.54 (1.4)	2.70 (6.3)	5.06 (24.6)	4.92 (23.2)
Imazethapyr	70	PRE	2.92 (7.5)	4.82 (22.2)	9.08 (81.5)	7.69 (58.2)
Imazethapyr	60	2-4 leaf stage	4.12 (16.0)	2.65 (6.0)	6.42 (40.3)	6.19 (37.4)
Imazethapyr	70	2-4 leaf stage	4.11 (15.9)	2.49 (5.2)	6.05 (35.6)	6.06 (35.8)
Imazethapyr	80	2-4 leaf stage	4.07 (15.6)	2.35 (4.5)	5.51 (29.4)	5.78 (32.4)
Imazethapyr + imazamox (RM)	60	2-4 leaf stage	4.07 (15.6)	2.37 (4.6)	7.04 (48.6)	6.54 (41.8)
Imazethapyr + imazamox (RM)	70	2-4 leaf stage	4.11 (15.9)	2.32 (4.4)	6.29 (38.6)	6.12 (36.4)
Imazethapyr + imazamox (RM)	80	2-4 leaf stage	4.04 (15.3)	1.85 (2.4)	5.48 (29.1)	5.55 (29.8)
Weedy check	-		4.17 (16.4)	6.73 (44.3)	12.19 (147.6)	10.14 (101.9)

Weed free	-		1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
SE (m) ±			0.05	0.07	0.14	0.13
CD at 5%			0.16	0.21	0.42	0.37

Original data given in parenthesis were subjected to square root $\sqrt{(x+1)}$ transformation.

Among the herbicidal treatments, pre-emergence application of pendimethalin +imazethapyr (RM) at 1250 g ha^{-1} proved to be superior over other treatments as first flush of weeds was effectively controlled by the combination of pendimethalin and imazethapyr associated with broad spectrum control of weeds by combination of these two herbicides having different modes of action.Hajebi et al. (2016) also reported that pre-emergence tank-mix application of pendimethalin 0.75 kg ha^{-1} + imazethapyr 0.075 kg ha^{-1} significantly reduced weed density and dry weight by 93 and 89%, respectively, compared with weedy check and resulted in higher weed control efficacy (~86%) in chilli.Kumar et al. (2019) and Kaur et al. (2020) also reported similar findings suggesting that sequential application of pendimethalin 1.0 kg ha^{-1} (PRE) +imazethapyr 50 g ha^{-1} (PoE) was observed to be more effective in reducing the weed density and dry weight.Similarly, post-emergence (2-4 leaf stage) application of imazethapyr alone and its combinations with imazamox at different doses proved good especially at 60 DAS because of effective control of second flush of weeds appeared at 10-15 DAS.

3.2. Weed Indices

Weed indices such as weed control index (WCI), herbicide efficiency index (HEI), weed management index (WMI), Agronomic management index (AMI) and integrated weed management index (IWMI)are calculated to evaluate bio-efficacy of herbicides against weeds in pea.The maximum weed control index at 30 DAS(91.5%) was recorded with pre-emergence application of pendimethalin + imazethapyr at 1250 g ha^{-1} *fb* pendimethalin + imazethapyr (PRE) at 1000 g ha^{-1} (87.80%).However, post-emergence (2-4 leaf stage) application of imazethapyr + imazamox (RM) at 80 g ha^{-1} gave the highest (94.6%) weed control index *fb*the same treatment at 70 g ha^{-1} (90.1%) at 60 DAS. Further, the lowest weed control index was recorded in clodinafop (1.22-5.64%) and pinoxaden(1.83-5.64%) both applied at 35 DAS at all crop growth stages (Table 5).

Table 5: Effect of weed control treatments on various weed control indices in field pea at different intervals

Treatment	Dose (g ha^{-1})	Time of application	Weed control index (%)		Weed Index (%)	HEI	WMI	AMI	IWMI
			30 DAS	60 DAS					
Clodinafop	60	35 DAS	1.22	5.64	45.0	0.11	1.87	0.87	1.37
Pinoxaden	50	35 DAS	1.83	5.64	46.7	0.08	1.26	0.26	0.76
Pendimethalin	1000	PRE	54.27	35.67	26.5	0.74	1.34	0.34	0.84
Pendimethalin + imazethapyr (RM)	800	PRE	81.10	72.01	8.7	2.98	1.16	0.16	0.66
Pendimethalin + imazethapyr (RM)	1000	PRE	87.80	80.36	6.6	4.46	1.09	0.09	0.59
Pendimethalin + imazethapyr (RM)	1250	PRE	91.46	85.78	5.5	6.99	1.16	0.16	0.66
Imazethapyr	70	PRE	54.27	49.89	23.3	1.08	1.08	0.08	0.58

Imazethapyr	60	2-4 leaf stage	2.44	86.46	14.7	4.95	0.77	-0.23	0.27
Imazethapyr	70	2-4 leaf stage	3.05	88.26	11.3	5.72	0.76	-0.24	0.26
Imazethapyr	80	2-4 leaf stage	4.88	89.84	10.0	6.86	0.78	-0.22	0.28
Imazethapyr + imazamox (RM)	60	2-4 leaf stage	4.88	89.62	14.8	6.85	0.79	-0.21	0.29
Imazethapyr + imazamox (RM)	70	2-4 leaf stage	3.05	90.07	11.0	7.93	0.87	-0.13	0.37
Imazethapyr + imazamox (RM)	80	2-4 leaf stage	6.71	94.58	10.4	14.77	0.85	-0.15	0.35
Weedy check	-		0.00	0.00	50.2	0.00			
Weed free	-		100.00	100.00	0.0	-	1.01	0.01	0.51

The lowest values of WMI (0.76), AMI (-0.23) and IWMI (0.26) were recorded with post-emergence application of imazethapyr at 70 g ha^{-1} (at 2-4 leaf stage), whereas, the highest WMI (1.87), AMI (0.87) and IWMI (1.37) was observed withclodinafop (60 g ha^{-1}) applied at 35 DAS. However, herbicide efficiency index (14.77) was recorded highest in case of post-emergence application (2-4 leaf stage) of imazethapyr +imazamox (RM) at 80 g ha^{-1} and lowest (0.08) with pinoxaden (50g ha^{-1}) applied at 35 DAS.

3.3. Crop growth parameter

The maximum dry weight of crop plant was recorded in pre-emergence application of pendimethalin +imazethapyr (RM) at 1250 g ha^{-1} (0.64 g plant^{-1}), which was at par with weed free (0.65 g plant^{-1}), pre-emergence application of pendimethalin +imazethapyr (RM) at 1000 g ha^{-1} (0.63 g plant^{-1}) and 800 g ha^{-1} (0.62 g plant^{-1}), pre-emergence application of pendimethalin at 1000 g ha^{-1} (0.56 g plant^{-1}) and post-emergence applications (2-4 leaf stage) of imazethapyr +imazamox (RM) at 60-80 g ha^{-1} at 30 DAS. Similarly at 60 DAS, the maximum dry weight (3.20 g plant^{-1}) was recorded in weed free, which was at par with post-emergence (2-4 leaf stage) applications of imazethapyr +imazamox (RM) at 70 and 80 g ha $^{-1}$, pre-emergence application of pendimethalin +imazethapyr (RM) at 800-1250 g ha^{-1}, pre-emergence application of pendimethalin at 1000 g ha^{-1} and 2-4 leaf stage application of imazethapyr at 80 g ha^{-1}. Post-emergence (2- 4 leaf stage) application of imazethapyr alone and its combinations with imazamox both applied at 60-80 g ha^{-1} caused significant reduction in plant height of field pea as compared with weed free, visible even at 30 DAS. At 30 DAS, the maximum height (11.67 cm) was recorded with pendimethalin +imazethapyr (RM) at 1250 g ha^{-1} applied as pre-emergence, which was statistically at par with weed free, weedy check along with clodinafop and pinoxaden both applied at 35 DAS, pre-emergence application of pendimethalin at 1000 g ha^{-1}, imazethapyr at 70 g ha^{-1} and pendimethalin + imazethapyr (RM) at 1000 and 800 g ha^{-1}. However, plant height did not differ significantly due to different weed control treatments at 60 DAS (Table 6).

Table 6: Effect of weed control treatments on plant dry matter (g/plant) and plant height (cm) of field pea at different intervals

Treatment	Dose (g ha^{-1})	Time of application	Plant dry matter (g plant^{-1})		Plant height (cm)	
			30 DAS	60 DAS	30 DAS	60 DAS

Clodinafop	60	35 DAS	0.40	2.29	10.83	36.50
Pinoxaden	50	35 DAS	0.45	2.33	11.17	36.33
Pendimethalin	1000	PRE	0.56	3.04	11.33	35.50
Pendimethalin + imazethapyr (RM)	800	PRE	0.62	2.98	11.00	35.83
Pendimethalin + imazethapyr (RM)	1000	PRE	0.63	3.04	11.00	36.17
Pendimethalin + imazethapyr (RM)	1250	PRE	0.64	3.16	11.67	36.50
Imazethapyr	70	PRE	0.43	2.19	10.83	35.17
Imazethapyr	60	2-4 leaf stage	0.51	2.42	10.33	36.33
Imazethapyr	70	2-4 leaf stage	0.52	2.56	10.17	36.67
Imazethapyr	80	2-4 leaf stage	0.53	2.74	9.67	35.17
Imazethapyr + imazamox (RM)	60	2-4 leaf stage	0.57	2.49	10.17	36.83
Imazethapyr + imazamox (RM)	70	2-4 leaf stage	0.60	2.62	10.17	36.67
Imazethapyr + imazamox (RM)	80	2-4 leaf stage	0.60	2.76	9.67	35.17
Weedy check	-		0.42	2.11	10.83	34.83
Weed free	-		0.65	3.20	11.00	37.00
SE (m) ±			0.03	0.22	0.34	1.13
CD at 5%			0.09	0.64	0.99	NS

The reduction in weed competition in field pea by the use of different herbicides not only favoured the crop growth by facilitating abundant availability of light, moisture, nutrients and space, but also reduced over all interference by different weed species (Singh and Tripathi, 2004; Bhullar et al., 2015;Kaur et al., 2020). The pre-emergence application of pendimethalin +imazethapyr (RM) gave excellent control (Hajebi et al., 2016) and suppression of weeds was probably effective against second flush of weeds at 15 DAS stage onwards due to persistence of imazethapyr for long period. These results are also in support with the research findings of Rakesh et al. (2016).

3.4. Yield and yield attributes

The maximum number of pods per plant was recorded with weed free plot (28.0 pods $plant^{-1}$) that was statistically at par with pre-emergence application of pendimethalin at 1000 g ha^{-1} (25.7 pods $plant^{-1}$), pendimethalin + imazethapyr (RM) at 800- 1250 g ha^{-1} (26.0 and 27.0 pods $plant^{-1}$), post-emergence (2-4 leaf stage) application of imazethapyr at 60, 70 and 80 g ha^{-1} (26.0, 26.3 and 26.3 pods $plant^{-1}$, respectively) and imazethapyr + imazamox (RM) at 60, 70 and 80 g ha^{-1} (26.7, 27.0 and 27.3 pods $plant^{-1}$, respectively). The lowest number of pods per plant (20.3 pods $plant^{-1}$) was recorded in weedy check (Table 7). While, the number of seeds per pod in field pea did not differ significantly due to different treatments of weed control, the highest shelling % was found in weed free (57.3%) which was statistically at par with pre-emergence application of 34 pendimethalin +imazethapyr (RM) at 800, 1000 and 1250 g ha^{-1} (55.3, 55.7 and 56.9 %), post-emergence (2-4 leaf stage) application of imazethapyr at 70 and 80 g ha^{-1} (54.6 and 55.1%, respectively) and imazethapyr +imazamox (RM) at 70 and 80 g ha^{-1} (54.7 and 55.3%, respectively). However, the lowest shelling % was found in weedy check (49.4 %). The highest seed yield (18.08 q ha^{-1}) was recorded in weed free which was statistically at par with pre-emergence application of pendimethalin +imazethapyr (RM) at 1000 g ha^{-1} and 1250 g ha^{-1} (16.88 and 17.95 q ha^{-1}, respectively), *fb* application of imazethapyr +imazamox (RM) at 80 &70

g ha^{-1} at 2-4 leaf stage (16.20 and 16.09 q ha^{-1}, respectively). Among the herbicidal treatments, the minimum seed yield (9.64 q ha^{-1}) of field pea was recorded with pinoxaden at 50 g ha^{-1}. Reduction in seed yield to the tune of 50% was recorded under the weedy check in comparison with the best herbicidal treatment pendimethalin +imazethapyr (RM) at 1250 g ha^{-1} applied as pre-emergence herbicide. The maximum harvest index was recorded with pre-emergence application of pendimethalin +imazethapyr (RM) at 1000 g ha^{-1} (62.3%) which was statistically at par with weed free (58.9%), pre-emergence application of pendimethalin +imazethapyr (RM) at 1250 and 800 g ha^{-1} (61.2 and 61.4%), pendimethalin at 1000 g ha^{-1} (55.4%) and all the treatments applied as post-emergence at 2-4 leaf stage. Among the herbicidal treatments, the minimum harvest index (47.7%) was recorded with the post-emergence application of pinoxaden at 50 g ha^{-1}.

Table 7: Effect of weed control treatments on growth parameters, yield and yield attributes in field pea

Treatment	Dose (g ha^{-1})	Time of application	Number of pods per plant	Number of seeds per pod	Shelling (%)	Seed yield (q ha^{-1})	Biological yield (q ha^{-1})	Harvest Index (%)
Clodinafop	60	35 DAS	21.33	6.7	50.3	9.95	17.05	58.3
Pinoxaden	50	35 DAS	20.67	6.7	50.9	9.64	20.25	47.7
Pendimethalin	1000	PRE	25.67	7.0	51.3	13.29	27.74	55.4
Pendimethalin + imazethapyr (RM)	800	PRE	26.00	7.3	55.3	16.51	26.90	61.4
Pendimethalin + imazethapyr (RM)	1000	PRE	27.00	7.7	55.7	16.88	27.12	62.3
Pendimethalin + imazethapyr (RM)	1250	PRE	27.00	7.7	56.9	17.95	27.96	61.2
Imazethapyr	70	PRE	21.67	6.7	52.7	13.86	21.95	57.2
Imazethapyr	60	2-4 leaf stage	26.00	7.7	54.3	15.03	27.34	56.6
Imazethapyr	70	2-4 leaf stage	26.33	8.0	54.6	15.04	27.54	58.3
Imazethapyr	80	2-4 leaf stage	26.33	8.3	55.1	15.27	27.97	58.4
Imazethapyr + imazamox (RM)	60	2-4 leaf stage	26.67	8.3	53.7	15.40	25.43	60.6
Imazethapyr + imazamox (RM)	70	2-4 leaf stage	27.00	8.0	54.7	16.09	26.25	61.3
Imazethapyr + imazamox (RM)	80	2-4 leaf stage	27.33	8.3	55.3	16.20	26.89	60.3
Weedy check	-		20.33	6.3	49.4	9.00	18.21	49.4
Weed free	-		28.00	9.0	57.3	18.08	30.75	58.9
SE (m) ±			1.07	0.6	0.0	0.52	1.03	2.8
CD at 5%			3.13	NS	2.8	1.50	3.00	8.2

The higher yield attributes under these treatments could be due to lesser crop-weed competition, which gave better environment for growth and development of crop.It confirmed the observations of Chaudhary et al. (2009), who also reported that the presence of weeds (weedy check) caused 7.15 q ha^{-1}(32.4%) reduction in grain yield and 6.66 q ha^{-}

^{1}(18.7%)reduction in straw yield in field pea.Meena et al. (2018) also reported that significantly higher seed yield of soybean was recorded with pendimethalin 30% EC + imazethapyr 2% SL premix 960 g ha^{-1} (3000 ml ha^{-1}) applied as pre-emergence and remained at par with pyroxasulfone 85 % WG 102 g ha^{-1}as PPI.Post emergence application of imazethapyr at 30-35 DAS were also found equally effective in increasing yield attributes of field pea (Singh and Angiras, 2004; Rana et al., 2013; Singh et al., 2013).Similar increase in yield through reduction in weed interference by the sequential application ofpendimathalin*fb* imazethapyr treatment was reported in dwarf field pea (Shalini and Singh, 2014) and chilli (Hajebi et al., 2016).

3.5. Economics of various treatments

The practical utility of any weed control measure can only be judged on the basis of net returns and output-input ratio. Excellent control of dominant broad leaf as well as grassy weeds without any adverse effect on crop resulting in higher grain yield might have caused superior economic returns in these herbicidal treatments. Pre-emergence application of pendimethalin + imazethapyr (RM) at 1250 g ha^{-1} gave the highest net return (Rs. 31461 ha^{-1}) *fb* the same treatment at 1000 and 800 g ha^{-1} (Rs. 28784 & 28061 ha^{-1}, respectively). The lowest net return (Rs. 7669 ha^{-1}) under herbicidal treatments was recorded with pinoxaden at 50 g ha^{-1} applied as post-emergence herbicide at 35 DAS. The highest BC ratio (2.36) was recorded with pre-emergence application of pendimethalin + imazethapyr (RM) at 1250 g ha^{-1}, while the lowest BC ratio (1.33) was recorded in weedy check (Table 8).

Table 8: Comparative economics of different weed control treatments

Treatment	Dose (g ha^{-1})	Time of application	Gross returns (Rs ha^{-1})	Cost of cultivation (Rs ha^{-1})	Net returns (Rs ha^{-1})	B:C
Clodinafop	60	35 DAS	30418	21425	8993	1.42
Pinoxaden	50	35 DAS	29769	22100	7669	1.35
Pendimethalin	1000	PRE	41026	21966	19060	1.87
Pendimethalin + imazethapyr (RM)	800	PRE	50361	22300	28061	2.26
Pendimethalin + imazethapyr (RM)	1000	PRE	51459	22675	28784	2.27
Pendimethalin + imazethapyr (RM)	1250	PRE	54651	23190	31461	2.36
Imazethapyr	70	PRE	42227	21640	20587	1.95
Imazethapyr	60	2-4 leaf stage	47243	21520	25723	2.20
Imazethapyr	70	2-4 leaf stage	46120	21640	24480	2.13
Imazethapyr	80	2-4 leaf stage	46826	21760	25066	2.15
Imazethapyr + imazamox (RM)	60	2-4 leaf stage	47002	22347	24655	2.10
Imazethapyr + imazamox (RM)	70	2-4 leaf stage	49083	22605	26478	2.17
Imazethapyr + imazamox (RM)	80	2-4 leaf stage	49455	22862	26593	2.16
Weedy check	-		27737	20800	6937	1.33
Weed free	-		55254	40000	15254	1.38

4. Conclusions

Pre-emergence application of pendimethalin +imazethapyr (ready-mix) at 1250 g ha^{-1} provided effective control of weeds similar to weed free conditions with highest yield (1795 kg ha^{-1})and benefit cost ratio (2.36).

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