Integration of Chemical and Manual Weed Management on Weed Density, Yield and Production Economics of Lentil (*Lens culinaris* Medikus)

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Abstract

A field study was conducted during *rabi*, 2010-11 and 2011-12 at Agricultural Research farm, BHU, Varanasi (U.P.) where five herbicides either as sole, integrated with mechanical weeding (MW) or sequentially applied were evaluated for efficacies of the herbicides on controlling weeds, their influences on yield and production economics on lentil **(***Lens culinaris* Medikus**)** variety HUL 57. Results revealed that, two hand weeding (HW) was the most effective method for weed control next to weed free. At 60 DAS however, lowest density and dry matter accumulation of all weed species were recorded with two hand weeding at 30 and 45 DAS followed by sequential/continuous application of Pendimethalin (PE) and Imazethapyr (post-emergence/POE) that remained statistically at par with Pendimethalin+MW in the case of BLWs and grasses and Chlorimuron ethyl+MW in respect of sedges. Maximum weed control efficiency (WCE) was achieved under two HW (83%) followed by Pendimethalin+MW at 45 DAS and continuous application of Pendimethalin+Imazethapyr (76% each). However, significantly highest yield (1365 kg ha^{-1}), highest pods $plant^{-1}$ (66.07), seeds pod^{-1} (1.94) and nodules $plant^{-1}$ (8.20) were recorded under Pendimethalin+MW which was comparable and significantly not different from Pendimethalin+Imazethapyr @ 37.5 g a.i. ha^{-1}. Among sole applications, Pendimethalin and Pendimethalin+Imazethapyr (pre-mixed) significantly suppressed broadleaved weeds but poorly controlled the sedges and grasses though it was better than control. In the economic factor, Pendimethalin+MW with highest net return and benefit:cost ratio (₹ 47521 ha^{-1} and 3.15) and lowest weed index (4.51) was comparatively better than all the treatments including control. This integrated treatment was found as the most profit-oriented and sustainable weed management system in lentil.

1. Introduction

Lentil, an ancient crop is now a crop of modern times in both developed and developing countries today (Brand et al., 2007). Lentil is cultivated as a *rabi* crop in India that contributed about 32% of world lentil production with a production of 0.94 million tonnes during 2010-11. However India's rank in productivity is low (591 kg ha^{-1}) which was 23rd in lentil and 98th in total pulses (Anonymous, 2012). Weed management in lentil is one of the important agronomic practice that can avoid significant yield loss if adequately done (Brand et al., 2012). Increased cost of manual weeding, its poor labour efficiency and scarcity during critical periods when labour utilization is diverted to other priority crops made herbicides very attractive in lentil. Herbicides have revolutionized agriculture all over the world and have played key role in enhancing productivity. They are accepted as an essential tool in weed management as they reduce labour requirement enormously and are easy and convenient to use. However, continuous use of chemical alone could be detrimental to the soil environment that poses threats to the microorganisms. Integrated weed management has the potential to restrict weed populations to manageable levels, reduce the environmental impact of individual chemical weed management practices, increase cropping system sustainability and reduce weed resistance to herbicides. In adopting chemical and manual integrated weed control method, economic factor is the most important factor. The fundamental economical principle for weed management is simple i.e. to act only if benefit exceeds the cost of cultivation. In view of the economic status of the crop and weak competition with the weeds, the present study was undertaken for evaluating the effect of integrated weed management on weed density, yield of lentil and the economic implication.

2. Materials and Methods

The research field lying at $25^0 18'$ N latitude and $88^0 36'$ E latitude at an altitude of 129 m from the mean sea level in the north gangetic alluvial plains. Total rainfall of 15 mm and 35 mm were received during lentil crop growing season of 2010-11 and 2011-12, respectively. Mean maximum and minimum weekly temperature was 15 to 39°C and 7 to 19°C respectively. Organic carbon, pH and electrical conductivity of the experimental soil was 0.60 %, 7.7 and 0.26 dsm^{-1} respectively while available NPK was 216, 26 and 236.46 kg ha^{-1}, respectively. All the plots were uniformly applied with 20 kg N, 40 kg P_2O_5, 30 kg K_2O and 15 kg S ha^{-1}. Sowing of lentil variety HUL 57 was done on November 15 in both the years. Treatments consisted of Weedy check (control); Weed free; Hand Weeding at 30 DAS and 45 DAS (*Khurpi* aided); Mechanical weeding at 30 DAS and 45 DAS (Twin wheel hoe); Quizalofop-p-ethyl 5% EC @ 50 g a.i. ha^{-1} at 40 DAS; Imazethapyr 10% SL @ 37.5 g a.i. ha^{-1} at 40 DAS; Chlorimuron ethyl 25% WP (PPI) @ 4 g a.i. ha^{-1}; Pendimethalin 30% EC (PE) @ 1 kg a.i. ha^{-1}; Pre-mixed Pendimethalin 30% EC+Imazethapyr 2% EC (PE) @ 0.75 kg a.i. ha^{-1}; Pre-mixed Pendimethalin 30% EC+Imazethapyr 2% EC (PE) @ 1 kg a.i. ha^{-1}; Chlorimuron ethyl @ 4 g a.i. ha-1 as PPI+ Quizalofop-p-ethyl @ 50 g a.i. ha^{-1} at 40 DAS; Chlorimuron ethyl 25% WP (PPI) @ 4 g a.i. ha^{-1}+Imazethapyr 10% SL @ 37.5 g a.i. ha^{-1} 40 DAS; Pendimethalin 30% EC (PE) @ 1 kg a.i. ha^{-1}+Quizalofop-p-ethyl 5% EC @ 50 g a.i. ha^{-1} 40 DAS; Pendimethalin 30% EC (PE) @ 1 kg a.i. ha^{-1} (PE)+Imazethapyr 10% SL @ 37.5 g a.i. ha^{-1} 40 DAS; Chlorimuron ethyl 25% WP (PPI) @ 4 g a.i. ha^{-1}+MW 45 DAS; Pendimethalin 30% EC (PE) @ 1 kg a.i. ha^{-1}+Mechanical weedding at 40 DAS. Weed samples were collected at 30, 60 DAS and at harvest by placing a quadrate (0.50×0.50 m^2) randomly in each plot and converted into square meter basis. Data for weed components were subjected to square root transformation ($\sqrt{(x+0.5)}$) for uniformity. Data analyses were done with RCBD using OPSTAT software of CCS, HAU, Hisar. The economic analyses were carried out by computing the market price of inputs and outputs of current rates.

3. Results and Discussion

3.1. Effect on weed density and biomass

Chenopodium album and *Solanum nigrum* (Broad leaved weeds/BLWs) and *Cyperus esculentus* (Sedge) were the predominant weed species in the experimental field. *Cynodon dactylon* represented the grass family with negligible presence during the experimental years (Table 1). Critical perusal on pooled data taken at 30 DAS indicated that, density and dry matter accumulation of broadleaved weeds were significantly lower in Pendimethalin and Pendimethalin+Imazethapyr (pre-mixed) associated treatments (2-5%) which were statistically at par at all rates of application. Sedges and grasses were not affected by the pre-emergence and PPI herbicides. At 60 DAS however, lowest density (48% sedge, 33% BLWs and 18% grass) (Table 2) and dry matter accumulation of all weed species were recorded under two hand weeding at 30 and 45 DAS followed by continuous application of Pendimethalin (PE) and Imazethapyr (POE) which was statistically at par with Pendimethalin+MW in the case of BLWs and grasses and Chlorimuron ethyl+mechanical weeding in respect of sedges. The weeds that emerged at the later stage were not serious as crop canopy smothered them and limited the harmful effect on crop under the PE herbicide treatments. Similar result was also communicated by Singh and Joshi (2011). Significantly highest weed control efficiency was achieved under two HW (83%) with season long weed suppression followed by Pendimethalin supplemented with mechanical weeding (Table 2). Khope et al. (2011) also reported that in chickpea two hand weeding gave highest WCE. Sole application of Chlorimuron ethyl recorded significantly lowest weed count and dry matter exhibiting a low WCE but was significantly better than weedy check. The poor efficiency of Chlorimuron ethyl could be attributed to the time of Chlorimuron ethyl application (PPI) as reports confirmed effective weed control with post-emergence application of Chlorimuron ethyl (Chauhan et al., 2012). Pendimethalin and pre-mixed Pendimethalin+Imazethapyr were not so effective on sedges and grasses but broadleaved weeds were effectively controlled by these pre-emergence herbicides at both 30 and 60 DAS.

3.2. NPK depletion

Amount of nutrients (nitrogen, phosphorus and potassium) depleted due to the influence of various weed management systems are depicted in Table 2. Significantly lower nitrogen phosphorus and potassium removal by weeds was observed in weed free and two hand weeding followed by Pendimethalin+Imazethapyr with significant differences among them whereas, significantly highest depletion by weeds was observed under Chlorimuron ethyl applied as PPI, but was significantly superior to weedy check. High weed intensity, low weed control efficiency, application time (PPI) and less efficacy of the herbicides on the total weed spectrum might have resulted to high nutrient depletion by weeds under this treatment. Two HW at 30 and 45 DAS and Pendimethalin+Imazethapyr were the least overall nutrient depleting treatments with regard to total NPK removal. Significantly lower weed count, dry matter accumulation and higher efficiency of nutrient uptake by crops might have attributed to the better performance by these treatments.

3.3. Effect on yield attributes

The yield attributes were significantly influenced by the different treatments, either sole or in integrated manner (Table 3). Significantly higher number of pods $plant^{-1}$ and seeds pod^{-1} were associated with two HW after weed free followed by Pendimethalin (PE) @ 1 kg a.i. ha^{-1}+Mechanical weeding at 40 DAS and Pendimethalin (PE) @ 1 kg a.i. ha^{-1}

Table 1: Effect of weed control treatments on weed density and dry matter accumulation (Pooled mean of two years)

Treatments details	Weed density at 30 DAS (m^{-2})			Dry matter accumulation at 30 DAS (g m^{-2})			Weed density at 60 DAS (m^{-2})			Dry matter accumulation at 60 DAS (g m^{-2})		
	BLWs	Sedges	Grasses	BLWs	Sedges	Grasses	BLWs	Sedges	Grasses	BLWs	Sedges	Grasses
Weedy check (control)	7.55 (56.50)	7.49 (55.67)	2.48 (5.67)	2.22 (4.45)	2.75 (7.08)	1.46 (1.67)	9.65 (92.67)	10.05 (100.50)	3.52 (12.00)	5.97 (35.20)	4.76 (22.13)	3.07 (8.97)
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
HW 30 DAS & 45 DAS	7.30 (52.83)	6.49 (41.67)	2.44 (5.47)	2.18 (4.23)	2.47 (5.60)	1.30 (1.20)	1.92 (3.20)	2.68 (6.67)	1.32 (1.33)	2.09 (3.85)	2.08 (3.83)	1.30 (1.25)
MW at 30 DAS and 45 DAS	7.25 (52.00	7.14 (50.50)	2.42 (5.33)	2.25 (4.58)	2.44 (5.45)	1.24 (1.05)	2.55 (6.00)	3.58 (12.33)	1.56 (2.00)	2.33 (4.93)	2.53 (5.92)	1.43 (1.57)
Quizalofop-p-ethyl @ 50 g a.i.ha^{-1} at 40 DAS (Q)	7.45 (55.00)	6.63 (43.50)	2.45 (5.50)	2.06 (3.73)	2.57 (6.10)	1.15 (0.82)	4.17 (16.87)	5.90 (34.33)	1.63 (2.17)	3.58 (12.35)	2.87 (7.72)	1.66 (2.28)
Imazethapyr @ 37.5 g a.i. ha^{-1} at 40 DAS (I)	7.35 (53.58)	6.89 (47.00)	2.42 (5.33)	2.11 (3.94)	2.53 (5.90)	1.05 (0.60)	3.81 (14.00)	3.72 (13.33)	1.68 (2.33)	2.89 (7.85)	2.77 (7.18)	1.57 (2.00)
Chlorimuron ethyl @ 4 g a.i. ha^{-1} as PPI (C)	6.07 (36.33)	6.87 (46.67)	2.12 (4.00)	2.03 (3.62)	2.40 (5.25)	1.17 (0.88)	7.31 (53.00)	6.61 (43.17)	2.27 (4.67)	4.27 (17.75)	3.34 (10.65)	1.97 (3.40)
Pendimethalin 30% EC @ 1 kg a.i.ha^{-1} as PE (P)	1.29 (1.17)	6.66 (43.83)	2.35 (5.00)	1.06 (0.62)	2.60 (6.27)	1.06 (0.63)	2.65 (6.50)	8.37 (69.50)	2.74 (7.00)	2.81 (7.38)	3.74 (13.50)	1.83 (2.88)
P+Imazethapyr 2 EC @ 0.75 g a.i. ha^{-1} as PE	1.48 (1.70)	6.58 (42.83)	2.42 (5.33)	1.15 (0.82)	2.48 (5.63)	1.43 (1.57)	2.52 (5.83)	8.56 (72.83)	2.54 (6.00)	2.49 (5.68)	3.72 (13.35)	1.58 (2.03)
P+Imazethapyr 2 EC @ 1 kg a.i. ha^{-1} as PE	1.22 (1.00)	7.09 (49.83)	2.42 (5.33)	1.06 (0.63)	2.57 (6.10)	1.11 (0.73)	2.42 (5.33)	8.33 (68.83)	2.64 (6.50)	2.47 (5.62)	3.66 (12.92)	1.60 (2.05)
C+Q	6.10 (36.67)	6.42 (40.67)	2.12 (4.00)	2.02 (3.58)	2.43 (5.40)	1.15 (0.85)	5.05 (25.00)	5.42 (28.83)	1.72 (2.50)	3.75 (13.53)	3.46 (11.47)	1.58 (2.10)
C+I	6.12 (37.00)	6.45 (41.17)	1.83 (2.83)	2.24 (4.52)	2.58 (6.17)	1.08 (0.68)	3.54 (12.00)	4.85 (23.00)	1.68 (2.33)	2.46 (5.55)	2.79 (7.27)	1.67 (2.28)
P+Q	1.29 (1.17)	6.68 (44.17)	2.27 (4.67)	1.07 (0.65)	2.75 (7.08)	1.09 (0.70)	2.04 (3.67)	4.92 (23.67)	1.73 (2.500	2.65 (6.50)	2.94 (8.13)	1.81 (2.80)
P+I	1.33 (1.27)	7.02 (48.83)	2.20 (4.33)	1.13 (0.77)	2.49 (5.70)	1.06 (0.63)	2.04 (3.67)	4.32 (18.17)	1.73 (2.50)	2.29 (4.75)	2.72 (6.88)	1.52 (1.82)
C+MW at 45 DAS	6.11 (36.83)	6.32 (39.50)	2.12 (4.00)	2.09 (3.85)	2.40 (5.25)	1.10 (0.72)	4.04 (15.83)	3.42 (11.17)	1.77 (2.67)	3.50 (11.75)	2.45 (5.50)	1.57 (2.02)
P+MW at 45 DAS	1.43 (1.55)	7.02 (48.83)	0.75 (4.50)	1.14 (0.80)	2.53 (5.90)	1.10 (0.72)	2.16 (4.17)	3.92 (14.83)	1.82 (2.00)	2.35 (5.03)	2.92 (8.02)	1.49 (1.77)
SEm±	0.14	0.20	0.06	0.06	0.21	0.04	0.12	0.17	0.07	0.13	0.11	0.06
CD (p=0.05)	0.42	0.58	0.17	0.18	0.61	0.10	0.34	0.49	0.21	0.38	0.33	0.16

Data on weeds are subjected to $\sqrt{(x+0.5)}$transformation ;Values within parentheses are original; DAS: Days after sowing; HW: Hand weeding; MW: Mechanical weeding; Q: Quizalofop-p-ethyl @ 50 g a.i.ha^{-1} at 40 DAS; I: Imazethapyr @ 37.5 g a.i. ha^{-1} at 40 DAS; C: Chlorimuron ethyl @ 4 g a.i. ha^{-1} as PPI; P: Pendimethalin @ 1 kg a.i.ha^{-1} as PE (P); PE: Pre-emergence; PPI: Pre-plant incorporation

(PE)+Imazethapyr @ 37.5 g a.i. ha^{-1} 40 DAS, respectively. Rest of the treatments showed no significant differences in the yield attributes, except sole Chlorimuron and Quizalofop-p-ethyl observed with comparatively lower values. The result is supported by the findings of Muhammad et al. (2007). Pendimethalin+MW and Pendimethalin+Imazathapyr showed statistically non-significant differences amongst them. Reduced weed density and dry matter accumulation at initial weed stage with pre-emergence spray of Pendimethalin and soil manipulation with mechanical weeding might have attributed to better yield attributes. Muhammad et al. (2010) also reported that hoeing involved treatments showed better yield attributes performance in chickpea.

3.4. Rhizobium-plant symbiosis

Results indicated that weed free, hand weeding and mechanical weeding (hoeing) comparatively encouraged the nodulation capacity of lentil as evident from Table 2. It is also noteworthy that, nodule formation was highly favoured with reduced or non-herbicide use. Possible reason may be due to season long weed suppression by two hand weeding and soil aeration and better soil structural manipulation as a result of chemical free mechanical weeding or inter cultivation. Ahemad

Table 2: Effect of weed control treatments on relative density, WCE and NPK depletion at crop harvest (Pooled mean of two years)

Treatments details	Relative density (%) at 30 DAS			Relative density (%) at 60 DAS			WCE (%)	Nutrient depleted (kg ha^{-1}) at crop harvest		
	BLWs	Sedges	Grasses	BLWs	Sedges	Grasses		N	P	K
Weedy check (control)	49	47	4	51	43	7	-	5.98 (35.32)	2.38 (5.15)	4.76 (22.13)
Weed free	0	0	0	0	0	0	100	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
HW 30 DAS & 45 DAS	43	52	5	48	33	18	83	2.65 (6.54)	1.24 (1.05)	2.19 (4.29)
MW at 30 DAS and 45 DAS	49	46	5	66	21	13	71	3.20 (9.73)	1.51 (1.79)	2.65 (6.51)
Quizalofop-p-ethyl @ 50 g a.i.ha^{-1} at 40 DAS (Q)	39	55	5	62	34	4	57	3.76 (13.67)	1.71 (2.42)	3.12 (9.22)
Imazethapyr @ 37.5 g a.i. ha^{-1} at 40 DAS (I)	47	49	5	45	48	7	67	3.31 (10.46)	1.53 (1.83)	2.88 (7.78)
Chlorimuron ethyl @ 4 g a.i. ha^{-1} as PPI (C)	52	45	4	47	49	4	50	4.10 (16.33)	1.80 (2.73)	3.32 (10.55)
Pendimethalin 30% EC @ 1 kg a.i.ha^{-1} as PE (P)	89	2	9	80	10	11	63	3.66 (12.89)	1.61 (2.10)	3.00 (8.52)
P+ Imazethapyr 2 EC @ 0.75 g a.i. ha^{-1} as PE	85	5	10	82	9	8	62	3.63 (12.68)	1.59 (2.02)	3.00 (8.49)
P+ Imazethapyr 2 EC @ 1 kg a.i. ha^{-1} as PE	88	2	10	84	7	9	69	3.49 (11.65)	1.54 (1.86)	2.88 (7.82)
C+Q	52	44	4	50	46	4	63	3.43 (11.24)	1.56 (1.93)	2.79 (7.27)
C+I	51	46	4	62	32	6	69	3.17 (9.55)	1.42 (1.51)	2.58 (6.16)
P+Q	89	3	8	80	12	9	70	3.18 (9.62)	1.43 (1.56)	2.68 (6.69)
P+I	92	2	6	74	15	11	76	2.97 (8.30)	1.36 (1.34)	2.51 (5.78)
C+MW at 45 DAS	47	49	4	41	52	7	70	3.58 (12.31)	1.62 (2.14)	2.99 (8.42)
P+MW at 45 DAS	90	3	7	56	35	9	76	2.91 (7.96)	1.38 (1.41)	2.49 (5.71)
SEm±	-	-	-	-	-	-	-	0.15	0.04	0.09
CD (p=0.05)	-	-	-	-	-	-	-	0.44	0.10	0.27

Data on weeds are subjected to $\sqrt{(x+0.5)}$ transformation; Values within parentheses are original; DAS: Days after sowing; HW: Hand weeding; MW: Mechanical weeding; Q: Quizalofop-p-ethyl @ 50 g a.i.ha^{-1} at 40 DAS; I: Imazethapyr @ 37.5 g a.i. ha^{-1} at 40 DAS; C: Chlorimuron ethyl @ 4 g a.i. ha^{-1} as PPI; P: Pendimethalin @ 1 kg a.i.ha^{-1} as PE (P); PE: Pre-emergence; PPI: Pre-plant incorporation; WCE=Weed Control Efficiency

and Khan (2010) also reported that herbicides decreased the symbiotic activity of lentil. *Rhizobium leguminosarum*, a bacterium responsible for nodulation of lentil and its symbiotic association with the leguminous plant was affected by the herbicides, decreasing the nitrogenase activity and biological nitrogen fixation by the crop. The result was in conformity with Vessey et al. (1988) who reported that, nitrogenase activities of the legumes were reduced by herbicides. Among the herbicides, Chlorimuron ethyl was most destructive to nodule formation in lentil. Punia et al. (2011) also reported 20-30% injury to legumes (clusterbean) and its nodule formation with Chlorimuron ethyl application. Pendimelthalin with supplemental mechanical weeding (hoeing) was the next best performing treatment after pure manual weed control

methods possibly due high tolerance of *Rhizobium spp.* to Pendimethalin. Weed biomass incorporated into the soil during mechanical hoeing might also helped the soil rhizobia degrade the chemicals and cause less harm to all the living biota.

3.5. Impact on yield

Hand weeding (HW) at 30 and 45 DAS (*khurpi* aided) showed significantly superior effect next to weed free. Kaur et al. (2009) also confirmed the same result when HW in lentil was done at 25 and 45 DAS. Among the treatments, two hand weeding gave significantly highest yield followed by Pendimethalin with sequential mechanical weeding (hoeing with twin wheel hoe) that remained statistically at par with Pendimethalin+Imazethapyr. Twice hand weeding and weed free exhibited non-significant difference among them, while two HW and Pendimethalin+MW were statistically at par. Pendimethalin+MW further showed its insignificance with Pendimethalin+Imazethapyr in the grain yield. Among the treatments, Chlorimuron ethyl applied sole registered the significantly lower yield but was higher than weedy check. Similar result of better effect of Chlorimuron ethyl over control in soybean yield was also reported by Sharma and Sharma (2000).

3.6. Weed index

Weed index as in Table 2 reflected that, weedy check resulted in yield loss to the tune of 56%. The yield reduction was possibly due to the high intensity of weeds that robbed off the nutrient supply, sunlight and water besides limited space for comfortable crop growth and development. Among the treatments, Chlorimuron ethyl alone (29%) applied as PPI and sole Quizalofop-p-ethyl (28.76%) applied as post-emergence resulted in highest yield loss next to control. There was little loss in two hand weeding and no loss in weed free. The finding is in conformity with Adak (2006) who reported the yield loss of 60% in lentil without weeding. Pendimethlin+Mechanical hoeing recorded lowest yield reduction after two hand weeding. Effective weed control with reduced weed flora and biomass could be attributed to the better performance in avoiding yield loss. Among the sole applied herbicides, pre-mixed Pendimethalin+Imazethapyr at both doses (0.75 and 1 kg ha^{-1}) showed least yield reduction.

3.7. Toxicity and injury to crop

Phytotoxicity and mechanical injury were judged/rated by way of visual observation on field emergence, wilting, crinkling of tender leaves, discolouration etc. All the pre-emergence

Table 3: Weed control treatments on nodule count at 60 DAS, yield attributes, grain yield, economics and phytotoxicity on lentil (Pooled mean of two years)

Treatments Details	Nodules plant^{-1}	Pods plant^{-1}	Seeds pod^{-1}	Yield (kg ha^{-1})	Net return (₹ ha^{-1})	BCR	Weed index(%)	Phyto-toxicity
Weedy check (control)	3.69	24.48	1.70	625.91	13352.61	1.71	56.21	-
Weed free	10.83	68.88	1.98	1429.67	41416.62	2.32	0.00	-
HW 30 DAS & 45 DAS	9.20	65.07	1.95	1389.47	42294.49	2.48	2.81	-
MW at 30 DAS and 45 DAS	8.03	58.88	1.88	1302.25	41777.52	2.69	8.89	#
Quizalofop-p-ethyl @ 50 g a.i.ha^{-1} at 40 DAS (Q)	4.62	42.33	1.75	1018.55	31185.54	2.49	28.76	1
Imazethapyr @ 37.5 g a.i. ha^{-1} at 40 DAS (I)	4.42	50.93	1.72	1115.90	37083.61	2.86	21.95	1
Chlorimuron ethyl @ 4 g a.i. ha^{-1} as PPI (C)	4.08	37.25	1.78	1010.10	32160.99	2.65	29.35	*
Pendimethalin 30% EC @ 1 kg a.i.ha^{-1} as PE (P)	5.98	58.35	1.88	1045.76	32725.47	2.58	26.86	*, 0
P+ Imazethapyr 2 EC @ 0.75 g a.i. ha^{-1} as PE	5.18	59.20	1.90	1152.52	38199.77	2.84	19.33	*, 0
P+ Imazethapyr 2 EC @ 1 kg a.i. ha^{-1} as PE	5.28	60.05	1.92	1194.17	39792.15	2.88	16.41	*, 0
C+Q	4.15	52.75	1.72	1034.42	31759.44	2.50	27.64	*, 2
C+I	4.34	55.92	1.78	1094.30	35740.10	2.77	23.43	*, 1
P+Q	4.81	57.87	1.89	1217.50	39764.60	2.78	14.84	*, 2
P+I	5.70	61.15	1.94	1295.97	44679.40	3.08	9.33	*, 1
C+MW at 45 DAS	4.93	54.07	1.70	1068.00	32144.34	2.43	25.23	*, #
P+MW at 45 DAS	8.20	62.33	1.94	1365.05	47520.73	3.15	4.51	*, #
SEm±	0.45	2.94	0.09	36.84	-	-	-	-
CD (p=0.05)	1.32	8.53	NS	106.80	-	-	-	-

DAS: Days after sowing; HW: Hand weeding; MW: Mechanical weeding; Q: Quizalofop-p-ethyl @ 50 g a.i.ha^{-1} at 40 DAS; I: Imazethapyr @ 37.5 g a.i. ha^{-1} at 40 DAS; C: Chlorimuron ethyl @ 4 g a.i. ha^{-1} as PPI; P: Pendimethalin @ 1 kg a.i.ha^{-1} as PE (P); PE: Pre-emergence; PPI: Pre-plant incorporation; 0: No injury (normal); 1: Stunted growth, recovered later; 2: Some standard loss and discolouration; #few plants mechanically injured; *delayed field emergence; Note: Cost of Inputs and outputs were computed on current market price at Varanasi.

herbicides delayed field emergence of the crop and all post-emergence herbicides showed either stunted growth, leaf discolouration or wilting. However, plants regained their normal growth after 20-30 days of application and did not cross the economic threshold level. Amongst the herbicides, most severe plant injury was inflicted with Chlorimuron ethyl applied either with Quizalofop-p-ethyl or Imazethapyr sequentially as both symptoms viz, late emergence and stunted plant growth were visually observed. Pendimethalin and pre-mixed Pendimethalin+Imazethapyr did not show post-application symptoms. Mechanical injury was observed with plants growing astray from the plant rows. The plants with still shallow roots were killed due to root disturbance during the inter cultivation (hoeing) operation. Similar findings on lentil phototoxicty due to herbicides and mechanical injury were also given by Kurstjens and Kroff (2001).

3.8. Economic implication

Economic analyses (Table 2) indicated that cost incurred in sole application of herbicides were comparatively less, but the low biological yield correspondingly resulted in low net return and BCR. Weed free and two hand weeding were significantly highest in grain yield and gross return, but due to higher cost of cultivation associated, the net return and BCR were correspondingly low. Comparison between single herbicides indicated that, pre-mixed Pendimethalin+Imazethapyr was the most profitable herbicide. Among the continuous herbicide applications, Pendimethalin (PE)+Imazethapyr (POE) was the best option as it fetched a fair net return and high BCR. Pendimethalin+mechanical weeding (hoeing) reflected highest net return and BCR which may be the best choice for integrated weed management. Similar profitability with the treatment in lentil was also reported by Kalpana (2010). Under Pendimethalin+mechanical hoeing, comparatively low cost of the herbicide, lesser labour requirement with more weeding coverage area in a short time particularly under sandy and clay loam soils and rainfed conditions may be reasons for profitability of the system. All the treatments recorded higher BCR than control.

4. Conclusion

The study suggested that, one pre-emergence herbicide (Pendimethalin @ 1 kg ha^{-1}) supplemented by one mechanical weeding (hoeing with twin wheel hoe) at 45 DAS could be the best option for integrated weed management in lentil under rainfed conditions.

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