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Herbicides for weed management in lentil under rainfed drought prone ecology of Bihar

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ABSTRACT

In context of the emerging challenge of weed management in lentil under rainfed drought prone ecologies in India, a field experiment was conducted in the winter seasons of 2012-13 and 2013-14 to evaluate the performance of different herbicides in lentil under rainfed conditions. Among the herbicidal treatments, the maximum plant height (40.5 cm), plant population (143.7 plants/m^2), branches per plant (5.67), pods per plant (59.03), nodules per plant (21.27), dry weight of nodules per plant (29.44 mg) and dry matter accumulation (486.30 g/m^2) of lentil at maturity were recorded in plots treated with pendimethalin (pre-emergence) followed by quizalofop-ethyl (post-emergence) at 750 g and 50 g/ha. Pendimethalin followed by quizalofop-ethyl recorded significantly lower weed index (12.97%) with higher grain yield (1741.0 kg/ha) as compared with control and it was closely followed by pendimethalin alone (14.64%). Imazamox plus imazethapyr caused severe crop phytotoxicity and the crop had a slow growth and reduced crop biomass. The maximum benefit cost ratio of 3.83 was recorded in the plot treated with pendimethalin at 750 g/ha (pre-emergence) as compared to other herbicides. Thus, pendimethalin alone and with quizalofop-ethyl were equally effective in controlling the broad-spectrum of weeds in lentil with high yield advantage.

Key words: Herbicides, Lentil, Phytotoxicity, Rainfed ecology, Weed control efficiency, Weed index

Weeds can grow faster and taller than short statured crops like lentil and inhibit tillering and branching when weed management practices are not used. They can curb sunlight and adversely affect photosynthesis as well as ultimate yield (Rao 2000). The losses in crops yields due to weed were estimated as 15-30% in wheat, 30-35% in rice and 18-85% in maize, sorghum, pulses and oilseeds (Mukhopadhyay 1992). Rao (1995) reported that the weeds are competitive and adaptable to all adverse environments. There is a severe competition between weeds and plants for nutrients, moisture, light and space which leads to a reduction of agricultural produce up to 45%. Recent estimates showed that annual yield loss due to overall weeds in India is 33% accounting nearly $ 309.37 million to Indian agriculture, which is more than the combined losses caused by insect, pests and disease. It has been further estimated that losses in crop yields due to weeds in advanced countries are 5% and in the least developed countries, about 25% (Gupta 2002). The loss caused by weeds in lentil production is considerable for two reasons, first, the lentil has a slow rate of development and, thus, is overwhelmed by weeds in the early stages of its development. Secondly, weeds are easily compatible with the lentil and grow without difficulty by utilizing soil moisture and plant nutrients in prevailing environmental conditions efficiently at its initial development stages (Bukun and Guler 2005). Besides yield loss, weeds also harbour certain insect, pest, which feed on prevailing crop and affect their economic yield (Singh *et al.* 2008). Therefore, weeds are of crucial importance and need to be reconsidered under experimentation at multi locational basis.

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Cultural practices are the backbone of an integrated weed management plan, but they alone may not be enough to secure adequate weed control in lentil fields. Mechanical weed control practices in lentils, such as harrowing or rotary hoeing in the fields after weed emergence, represent a viable alternative. But the mechanical approach can cause injury to lentil shoots and roots leading to reduced plant stands. Chemical weed control can help reduced-till or no-till lentil producers to manage weeds. However, the applicability and success of herbicides in lentil fields depends on the cropping system, land preparation methods, soil conditions, and weed problems. Risk of crop injury due to soil applied herbicides is particularly important in areas with dry climate and prolonged winters. Furthermore, weed management in lentil is of particular importance as this crop is generally considered to be a poor competitor due to its slow establishment and limited vegetative growth (Chaudhary *et al*. 2011). Thus weed management through the use of various herbicides at local and regional level should be taken under consideration.

Among the different herbicides, pendimethalin is a group of dinitroaniline herbicides used as selective pre-emergence to control annual grasses and broad-leaved weeds in pulse crops. It interferes with the mitotic process by inhibiting the formation of the microtubule protein, tubulin (Appleby *et al*. 1989). It is also a low mobile herbicide, having low water solubility and low volatility (Schleicher *et al*. 1995). Persistence of it in the soil is affected by soil temperature, cultivation and moisture conditions (Gasper *et al*. 1994). Imazethapyr acts by inhibiting the enzyme acetolactate synthase (ALS) and is a selective systemic herbicide. It may be used alone or in co-formulation with imazamox or pendimethalin to control a broad spectrum of broad-leaved and grassy weeds in pluses. Padmaja *et al*. (2013) stated that imazethapyr 75 g/ha applied at 20 DAS significantly reduced the density and biomass of both dicot and monocot weeds recorded at 30 DAS compared to weedy check followed by pendimethalin 750 g/ha as pre-emergence in Andhra Pradesh, India. But still there is a lack of proper location specific herbicidal recommendation, explicitly in lentil to overcome labour shortage and mechanical crop damage. Furthermore, Zollinger (2006) specified very limited availability of post-emergence herbicides for lentils. Therefore there is a need of revised experimentation to evaluate suitable herbicides to manage weeds in lentil.

A fundamental reason for the widespread use of chemical herbicides in modern agriculture is their ability to control selective and immediately a wide spectrum of weeds in a variety of crops and in some situations where all other method fail or can not be adopted (Mukhopadhyay 1992). The hike in labour cost also led to increase use of herbicides. Thus, it has been a common observation that in recent years, farmers have started adopting chemical weed control themselves. The advent of chemical herbicides brought about a revolutionary change in weed management in the era of increased mechanization and intensive cropping programmes to increase yield. Application of herbicide is easy, rapid and more effective for controlling weeds over cultural and mechanical methods. Therefore, a few promising herbicides including pendimethalin, imazethapyr, imazamox plus imazethapyr, quizalofop-ethyl and metribuzin were evaluated in this study for their efficacy in managing weeds in lentil.

MATERIALS AND METHODS

A field experiment was conducted in the winter seasons of 2013-14 and 2014-15 on loam, Typic Ustochrept soil at the research farm of Bihar Agricultural University, Sabour, Bihar, India. The experimental site is located between $25^0$23'N latitude and $87^0$07'E longitude with the elevation of 37.19 m under sub-tropical climatic conditions characterized with hot desiccating summer, cold winter and moderate rainfall. The area is known as Ganges river flood plain. The soil at the experimental field at 0-15 cm depth was loam in texture with a bulk density of 1.43 g/cc, organic carbon content of 0.63% with low in nitrogen and phosphorus and medium in potassium status. The experimental site belongs to sub-tropical humid climate with an average annual rainfall of 1460 mm, mostly precipitated during June to September. The mean maximum and minimum temperature varied 20.2 to 31.3 °C and 5.2 to 15.3 °C respectively during the experimental months (November to March). Although, the rainfall was distributed mostly from July to September, irrespective of all years, but during the experimentation, maximum rainfall (36.5 mm) was recorded in the month February, 2014. The highest value of monthly mean maximum relative humidity (98.0%) was observed in the months of December, 2013.

The previous crop in the experimental field was rice. Lentil variety '*HUL-57*' was sown in the last week of October manually with a hand plough at 30 cm row spacing using a seed rate of 25 kg/ha. For both the seasons, the plot size was 6 x 4 m. Recommended dose of fertilizers (23:60:20 kg N: P_2O_5: K_2O/ha) were applied through di-ammonium phosphate and muriate of potash at the time of seed bed preparation and no irrigation was given to the crop throughout the crop season. The experiment had treatments of imazethapyr at 20 and 40 g/ha each applied at 15 and 30 days after sowing (DAS), pendimethalin at 750 g/ha as pre-emergence (PE), pendimethalin PE at 750 g/ha followed by quizalofop-ethyl post-emergence (PoE) and 50 g/ha, imazamox + imazethapyr at 30 g/ha at 30 DAS, metribuzin at 250 g/ha as PE, weedy (non-treated) and weed free checks. In each year, the experiment was laid out in randomized block design with three replications. All other agronomic practices were kept uniform in each treatment. Herbicides were applied with a knapsack foot sprayer fitted with a flat fan nozzle using 500 l/ha spray volume. Data were recorded from randomly selected quadrats of 1.0 x 1.0 m size at 30, 60 and 90 DAS. Species-wise weed density and their biomass, crop plant population, yield attributes and seed yield were recorded. Biomass of weeds was recorded after drying the samples in an oven at 70 ^{0}C for 48 hours. Weed control efficiency (on weed dry weight basis) and weed index were also computed. Cost of cultivation and net return were computed on the basis of prevailing rates of labour, inputs, and the produce. The data were analyzed statistically using analysis of variance (Steel *et al.* 1997) in Microsoft Excel and means were compared using the least significant difference (LSD) test.

RESULTS AND DISCUSSION

Effect on weeds

Altogether 18 different species of weeds were observed in the experimental site. Among broad-leaved weeds, *Chenopodium album*, *Rumex dentatus, Vicia sativa, Vicia hirsuta, Medicago denticulate, Melilotus indica, Anagallis arvensis, Coronopus didiymous* and *Fumaria parviflora* were dominant. Among grassy weeds, *Polypogon monosplensis, Phalaris minor* and *Cynodan dactylon* were dominant. Whereas, among sedges, *Cyperus rotundus* only was major weed. The density of grassy, broad-leaf weeds and sedges recorded at different crop growth stages varied significantly due to different weed management practices (**Table 1**). The density and biomass of weeds were lower with imazamox + imazethapyr applied at 30 DAS, reflecting high weed control efficiency but with lower yield of lentil. Among the herbicidal treatments, pendimethalin PE and quizalofop-ethyl PoE resulted into second highest weed control efficiency with higher yield of lentil and lowest weed index (12.97%) over control (**Table 2**). It was closely followed by sole pendimethalin PE (WI 14.64%). In other study also, herbicides have been reported effective lentil (Elkoca *et al.* 2004).

The weed index explained 99.96% variability in lentil seed yield (R^2 = 0.9996). The treatment with higher weed index produced lower seed yield of lentil, as weed index expresses the reduction in yield due to the presence of weeds in comparison with weed-free situation (**Figure 1**). The weed control efficiency explained 97.34% variability in lentil seed yield (R^2 = 0.9734). The line in the graph (**Figure 2**) also represented initial increas then a decreasing tendency from 60% weed control efficiency point. The treatments, which had higher weed control efficiency produced more seed yield with less crop weed competition.

Effect on crop

Table 1. Effect of herbicides on density of grassy, broad-leaved weeds and sedges at different stages of crop growth (pooled data of two years)

Treatment	Weed density (no./m^2)											
	30 DAS				60 DAS				90 DAS			
	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total	Grassy	BLW	Sedges	Total
Imazethapyr 20 g/ha 15 DAS	3.3 (10.0)	2.9 (7.7)	3.5 (11.0)	5.4 (28.7)	2.8 (7.0)	2.8 (7.0)	3.3 (9.7)	5.0 (23.7)	3.3 (9.7)	3.0 (8.0)	3.5 (11.3)	5.5 (29.0)
Imazethapyr 40 g/ha 15 DAS	3.1 (8.5)	2.7 (6.3)	3.3 (9.7)	5.0 (24.5)	2.7 (6.3)	2.6 (6.0)	3.0 (8.3)	4.6 (20.7)	3.0 (8.0)	2.6 (5.7)	3.0 (8.3)	4.8 (22.0)
Imazethapyr 20 g/ha 30 DAS	4.9 (22.7)	4.6 (20.3)	4.7 (21.0)	8.1 (64.0)	3.1 (8.3)	3.0 (8.0)	3.3 (9.7)	5.2 (26.0)	4.6 (20.0)	4.2 (16.7)	3.9 (14.7)	7.2 (51.3)
Imazethapyr 40 g/ha 30 DAS	5.0 (24.3)	4.6 (20.0)	4.8 (22.3)	8.2 (66.7)	2.9 (7.3)	2.8 (6.7)	3.2 (9.0)	4.9 (23.0)	4.3 (17.3)	3.9 (14.7)	3.4 (10.7)	6.6 (42.7)
Pendimethalin 750 g/ha PE	3.7 (12.7)	2.9 (7.7)	3.9 (14.3)	6.0 (34.7)	3.6 (12.3)	3.0 (8.3)	3.6 (12.3)	5.8 (33.0)	3.8 (13.3)	2.7 (6.3)	3.6 (11.7)	5.7 (31.3)
Pendimethalin *fb* quizalofop-ethyl 750 g + 50 g/ha PE+ PoE	3.5 (11.3)	2.9 (7.7)	3.6 (12.3)	5.7 (31.3)	3.5 (11.3)	3.0 (8.3)	3.5 (11.0)	5.6 (30.7)	3.4 (10.3)	2.7 (6.7)	3.1 (8.7)	5.2 (25.7)
Imazomox 30 g/ha 30 DAS	4.9 (23.0)	4.4 (18.3)	4.8 (22.0)	8.0 (63.3)	2.5 (5.3)	2.5 (5.3)	2.3 (4.3)	4.0 (15.0)	3.2 (9.7)	2.2 (4.0)	2.1 (3.7)	4.3 (17.3)
Metribuzin 250 g/ha PE	3.6 (12.0)	3.2 (9.0)	3.8 (13.7)	6.0 (34.7)	3.8 (13.3)	3.1 (8.7)	3.6 (12.0)	5.9 (34.0)	3.6 (12.3)	2.8 (7.0)	3.5 (11.3)	5.6 (30.7)
Weedy check	5.4 (28.0)	5.4 (28.7)	5.4 (28.7)	9.3 (85.3)	5.5 (29.3)	5.6 (30.7)	5.5 (29.3)	9.5 (89.3)	5.8 (33.0)	5.0 (24.0)	5.2 (26.3)	9.2 (83.3)
Weed free	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
LSD (p=0.05)	0.55	0.55	0.50	0.53	0.42	0.60	0.56	0.53	0.63	0.53	0.54	0.51

DAS=Days after seeding PE = Pre-emergence; PoE=Post-emergence; BLW= Broad-leaved weeds; *fb* = Followed by

All weed management practices significantly increased the growth parameters and yield attributes of lentil as compared to the weedy check (**Table 3 and 4**). Among the herbicidal treatments, plots treated with pendimethalin PE followed by quizalofop-ethyl PoE documented maximum plant height (40.5 cm), plant population (143.7/m^2), branches/plant (5.67), pods/plant (59.03), nodules/plant (21.27), dry weight of nodules/plant (29.44 mg), and dry matter accumulation of lentil at maturity (486.30 g/m^2). The maximum seed yield (2.01 t/ha) was attained in the weed free check (**Table 4**), while it was minimum in the plots treated with imazamox plus imazethapyr (176 kg/ha), which was even less than the weedy check (1.05 t/ha). Hand weeding is an effective practice in traditional lentil growing areas, but it is not feasible on large areas (Gollojeh *et al.* 2013) because it is labour-intensive and expensive operation (Mohamed *et al.* 1997). The use of herbicides can eliminate weeds at early stages and prevent the yield losses successfully. Pendimethalin alone and in combination with quizalofop-ethyl being equally effective against weeds in lentil recorded 1.71 and 1.74 t/ha seed yield, respectively (**Table 4**).

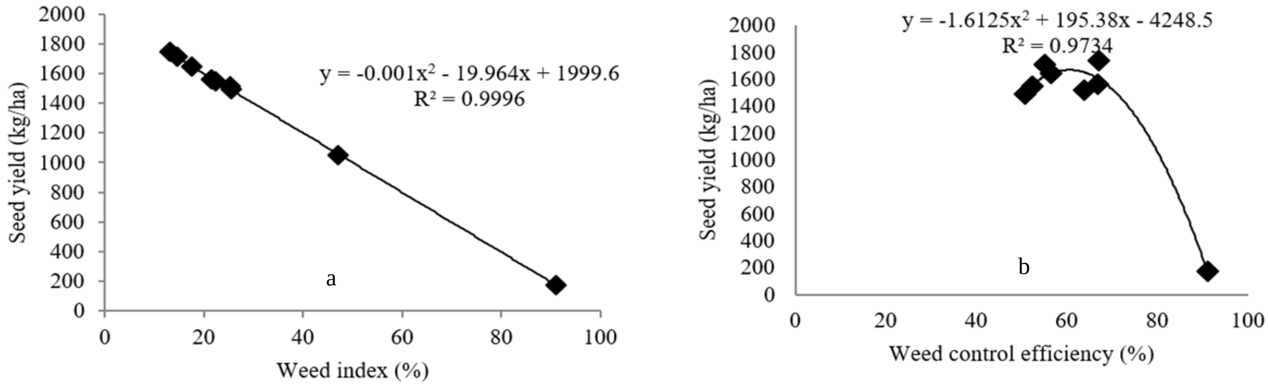

Figure 1. Relationship between seed yield with weed index (a) and weed control efficiency (b) in lentil

Table 2. Effect of herbicides on weeds in lentil (pooled data of two years)

Treatment	Weed biomass (g/m^2) 90 DAS	Weed control efficiency (%) 90 DAS	Weed index (%)
Imazethapyr 20 g/ha 15 DAS	345.3	52.5	22.3
Imazethapyr 40 g/ha 15 DAS	312.3	56.5	17.4
Imazethapyr 20 g/ha 30 DAS	356.7	50.8	25.4
Imazethapyr 40 g/ha 30 DAS	241.3	66.8	21.5
Pendimethalin 750 g/ha PE	327.7	55.1	14.6
Pendimethalin *fb* quizalofop-ethyl 750 g *fb* 50 g/ha PE+ PoE	242.0	67.0	13.0
Imazomox 30 g/ha 30 DAS	64.7	91.0	90.9
Metribuzin 250 g/ha PE	262.7	63.7	25.3
Weedy check	731.3	0.0	47.1
Weed free	0.0	100.0	0.0
LSD (p=0.05)	64.3	6.3	17.1

DAS=days after seeding' PE = Pre-emergence; PoE=Post-emergence

Table 3. Effect of different herbicides on growth and development of lentil at maturity in rice-lentil cropping system (pooled data of two years)

Treatment	Crop density (m^2)	Plant height (cm)	Branches/ plant (no.)	Nodules/ plant (no.)	Dry weight of nodules (mg/plant)	Dry matter accumulation (g/m^2)
Imazethapyr 20 g/ha 15 DAS	133.7	38.2	4.67	18.1	24.5	386.7
Imazethapyr 40 g/ha 15 DAS	139.0	38.9	4.93	16.7	23.1	386.4
Imazethapyr 20 g/ha 30 DAS	132.7	37.0	4.63	19.3	26.6	361.5
Imazethapyr 40 g/ha 30 DAS	135.7	38.2	5.00	19.1	26.1	360.5
Pendimethalin 750 g/ha PE	142.7	40.5	5.57	19.2	26.0	450.4
Pendimethalin *fb* quizalofop-ethyl 750 g *fb* 50 g/ha PE+ PoE	143.7	40.5	5.67	21.4	29.4	486.3
Imazomox 30 g/ha 30 DAS	46.0	19.0	3.77	9.1	11.9	87.7
Metribuzin 250 g/ha PE	130.0	36.1	4.40	18.2	25.2	431.5
Weedy check	124.3	34.6	3.93	20.4	20.4	363.0
Weed free	145.7	41.7	5.90	23.9	33.1	510.7
LSD (p=0.05)	11.9	2.6	1.07	2.3	3.9	100.0

Commercial mix formulation of imazamox + imazethapyr recorded lowest seed yield due to severe crop phytotoxicity. The crop growth was drastically reduced due to the application of imazamox + imazethapyr. Weeds allowed to grow throughout the crop season resulted into yield reduction of 47.1%. The yield reduction might be due to high intensity of weeds that robbed off the nutrient supply, sunlight, and water besides limited space for crop growth and development. Pendimethalin followed by the sequential application of quizalofop-ethyl proved more effective due to better weed management at an early stage by pendimethalin as well as follow up weed control by post-emergence application of quizalofop-ethyl. Yadav *et al.* (2013) also reported that pendimethalin 750 g/ha *fb* one hand weeding produced maximum grain yield and it was statistically at par with pendimethalin 1000 g/ha as well as weed free.

Pearson's correlation study also confirmed that weed index is significantly correlated with pod/plant (r = -0.99, p<0.01), no. of grains/pod (r = -0.92, p<0.01), grain yield (r = -1.0, p<0.01), straw yield (r = -0.85, p<0.01) and harvest index (r = -0.88, p<0.01) (**Table 5**).

Economics

Lentil under weed free conditions gave maximum net returns of ` 54,693/ha (**Table 6**). Among herbicidal treatments, the maximum net

Table 4. Effect of weed management practices on yield and yield attributing character of lentil (pooled of two years)

Treatment	Pods /plant	Grains /pod	Test weight (g)	Biological yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)
Imazethapyr 20 g/ha 15 DAS	51.63	1.43	23.6	3.87	1.55	2.32	40.10
Imazethapyr 40 g/ha 15 DAS	56.30	1.53	23.7	3.88	1.64	2.24	42.32
Imazethapyr 20 g/ha 30 DAS	47.93	1.47	23.7	3.65	1.49	2.16	40.99
Imazethapyr 40 g/ha 30 DAS	53.17	1.57	23.7	3.61	1.56	2.05	44.34
Pendimethalin 750 g/ha PE	57.97	1.60	23.8	4.56	1.71	2.84	38.61
Pendimethalin *fb* quizalofop-ethyl 750 g *fb* 50 g/ha PE + PoE	59.03	1.57	23.5	4.91	1.74	3.17	35.71
Imazomox 30 g/ha 30 DAS	12.73	1.17	23.8	0.87	0.18	0.69	20.32
Metribuzin 250 g/ha PE	46.83	1.37	23.8	4.15	1.52	2.63	36.09
Weedy check	38.33	1.33	23.5	3.63	1.05	2.58	28.97
Weed free	63.50	1.60	24.2	5.02	2.01	3.01	40.47
LSD (p=0.05)	10.48	0.34	NS	1.02	0.35	0.90	10.70

Table 5. Pearson's correlation among pod/plant, no. of grains/pod, grain yield, straw yield, harvest index and weed index

	Pods/plant	Grains/pod	Grain yield	Straw yield	Harvest index	Weed control efficiency	Weed index
Pods/plant	1						
Grains/pod	0.944**	1					
Grain yield	0.991**	0.912**	1				
Straw yield	0.849**	0.720*	0.854**	1			
Harvest index	0.867**	0.840**	0.872**	0.531	1		
Weed control efficiency	0.031	0.141	0.054	-0.203	0.032	1	
Weed Index	-0.993**	-0.916**	-1.000**	-0.851**	-0.877**	-0.050	1

Table 6. Economics of lentil production as influenced by herbicide treatments (pooled of two years)

Treatment	Gross return (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	Net return (x10^3 `/ha)	Benefit cost ratio
Imazethapyr 20 g/ha 15 DAS	62.05	17.53	44.52	2.54
Imazethapyr 40 g/ha 15 DAS	65.20	17.89	47.31	2.64
Imazethapyr 20 g/ha 30 DAS	59.56	17.53	42.03	2.40
Imazethapyr 40 g/ha 30 DAS	61.74	17.89	43.84	2.45
Pendimethalin 750 g/ha PE	69.55	18.14	51.41	2.83
Pendimethalin *fb* quizalofop-ethyl 750 g *fb* 50 g/ha PE+ PoE	71.53	19.58	51.94	2.65
Imazomox 30 g/ha 30 DAS	8.37	17.55	-9.18	-0.52
Metribuzin 250 g/ha PE	61.95	17.62	44.32	2.52
Weedy check	45.30	16.76	28.55	1.70
Weed free	80.59	25.90	54.69	2.11
LSD (p=0.05)	6.53	-	6.53	0.53

return of ` 51,945/ha and B-C ratio of 2.65 were recorded with pendimethalin PE followed by sequential application of quizalofop-ethyl PoE. However, the highest B-C ratio was achieved in the plots applied with pendimethalin alone. Application of pendimethalin after sowing of lentil has earlier been reported weak for the control of broad-leaved weeds (61%) whereas, it was effective (97%) against narrow-leaved weeds along with maximum returns (Chaudhary *et al*. 2011 and Ali *et al*. 2014). Correspondingly, Yadav *et al*. (2013) reported lowest density and biomass of weeds due to pendimethalin as pre-emergence *fb* one hand weeding, which was more economical but statistically at par with pendimethalin in producing seed yield of lentil. These findings also corroborate the other such findings elsewhere (Turk and Tawaha 2001, Jain 2007). They exhibited that the highest gross returns, net returns and B:C ratio was recorded by pendimethalin 750 g/ha PE *fb* one hand weeding under pulse crops. Every herbicidal treatment had a yield advantage over weedy check except imazamox + imazethapyr application. Ahmad *et al.* (1996), Mohamed *et al.* (1997), Stork (1998) and Fazal *et al*. (1999) also reported superiority of herbicides over weedy check. Pendimethalin followed by quizalofop-ethyl and pendimethalin alone could be the two better options as they fetched a fair net return and high B:C ratio.

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