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**Lingutla Sirisha**  
 PG Scholar, Bihar Agricultural  
 University, Sabour, Bhagalpur,  
 Bihar, India

**Birendra Kumar**  
 Assistant Professor- Department  
 of Agronomy, Bihar Agricultural  
 University, Sabour, Bhagalpur,  
 Bihar, India

**Sanjay Kumar**  
 Associate Professor- Department  
 of Agronomy, Bihar Agricultural  
 University, Sabour, Bhagalpur,  
 Bihar, India

**Sunil Kumar**  
 Assistant Professor, Department  
 of Soil science and Agricultural  
 Chemistry, Bihar Agricultural  
 University, Sabour, Bhagalpur,  
 Bihar, India

**Subrat Keshori Behera**  
 Assistant professor, Department  
 of Statistics, Bihar Agricultural  
 University, Sabour, Bhagalpur,  
 Bihar, India

**T Chattopadhyay**  
 Assistant professor, Department  
 of Plant Breeding and Genetics,  
 Bihar Agricultural University,  
 Sabour, Bhagalpur, Bihar, India

**Corresponding Author:**  
**Birendra Kumar**  
 Assistant Professor- Department  
 of Agronomy, Bihar Agricultural  
 University, Sabour, Bhagalpur,  
 Bihar, India

## Effect of pre and post emergence herbicidal application on weed dynamics and yield in lentil (*Lens culinaris*)

**Lingutla Sirisha, Birendra Kumar, Sanjay Kumar, Sunil Kumar, Subrat Keshori Behera and T Chattopadhyay**

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### Abstract

Lentil is one of the early domesticated species belongs to genus *Lens* of the Fabaceae family. Among all the biotic factors, weed infestation is being an adverse impact on growth and yield due to lentil short stature, low branching, lack of protective canopy and it's unable to smother the weeds. Although, applying pre emergence herbicides, in many circumstances early weed control herbicides are not that much efficient for attaining higher yields due to lentil is long duration crop and critical weed competition upto 40-60 DAS. Sequence use of pre and post-emergence herbicides and application of post-emergence herbicides may help in controlling the weeds at later stages of crop growth period. Therefore, the experiment was initiated to find out best weed control practices among 13 treatments considered in this research to get higher yields in lentil. Out of 13 treatments, weed free treatment produced significantly higher grain yield and straw yield and pendimethalin *fb* quizalofop-ethyl + imazethapyr and oxyflurofen *fb* quizalofop-ethyl + imazethapyr were statistically at par with weed free treatment. Weed densities and biomass of different weeds were recorded significantly lower in pendimethalin *fb* quizalofop-ethyl + imazethapyr, oxyflurofen *fb* quizalofop-ethyl + imazethapyr and imazethapyr + imazomox at 60 DAS and at harvest. Ultimately, it can be concluded that, application of pendimethalin *fb* quizalofop-ethyl + imazethapyr and oxyflurofen *fb* quizalofop-ethyl + imazethapyr in lentil brings in enhancing grain yield and achieving more net returns apart from suppressing the weeds through higher weed control efficiency and lower weed index.

**Keywords:** Grain yield, straw yield, weed free, weed control efficiency, pendimethalin *fb* quizalofop-ethyl + imazethapyr, oxyflurofen *fb* quizalofop-ethyl + imazethapyr and imazethapyr + imazomox

### Introduction

Lentil is one of humanity's oldest crops and is believed first it has been domesticated and cultivated in the Fertile Crescent of the Near East (Sonnante *et al.* 2009) <sup>[20]</sup>. Lentil is an parts of the world, particularly in parts of Asia continent. , where it represents an important human protein source (Sarker and Erskine 2006) <sup>[17]</sup>. The major economic product is seed which has relatively rich protein (24-26%), fat (1.3%); ash (2.2%); fibre (3.2%); carbohydrate (57%). Lentils are short in stature compared to most cereal and oilseed crops grown on the Canadian prairies. Lentils exhibit a slow growth rate, particularly early in the growing season, with slow canopy closure (Brand *et al.* 2007, Kirkland *et al.* 2000) <sup>[16, 12]</sup>. Thus, the lentil canopy is often sparse early in the season and weeds are able to occupy space in the canopy and compete against the lentil crop for resource acquisition (Elkoca *et al.* 2005) <sup>[9]</sup>. These factors make lentil a weak competitor against weeds, and weed control is major significant limitations in lentil production worldwide (Brand *et al.* 2007) <sup>[6]</sup>. Yield losses in lentil due to weed competition have been estimated at between 25 and 80% (Ball *et al.* 1997, Boerboom and Young 1995, Swanton *et al.* 1993) <sup>[4, 5, 22]</sup>. By practicing many agronomic management practices we can increase the yields. To attain higher productivity good weed control during the critical weed competition period. By practicing the cultural and mechanical methods alone weeds can't be controlled due to lentil short stature, low branching ability, lack of protective canopy it's unable to smother the weeds. Based on effectiveness and economics, weed management methods may depend. Due to non-availability of labour at right time and increased cost for manual labour, the chemical control of weeds plays an important role.

The herbicides control practices control the weeds timely and effectively, but also it is an effective way in reduction of cost of controlling weeds., irrespective of the situations. Even though farmers applying pre emergence herbicides, in many circumstances early weed control herbicides are not that much efficient for attaining higher yields due to lentil is long duration crop and critical weed competition is upto 40-60 DAS (Days After Sowing). Sequence use of pre and post-emergence herbicides and application of post-emergence herbicides may help in controlling the weeds at later stages of crop growth period. In India only about 15-20% of the lentil cultivated area weeds are controlled by herbicide usage. The crop yields may reduced due to high infestation of weeds during critical growth period hence it is difficult for effective control of weed flora through cultural methods and manual weeding. Beside this, non availability of labour at right time and high wages of labour manual weeding is also problematic in controlling the weeds, by usage of pre and post-emergence herbicide weed control has become the preferred method of weed control for long duration crops like lentil. Considering the effective weed management practices, this research mainly focused to find out best weed control practices to get higher yields of lentil by using 13 herbicidal combinations to reduce crop-weed competition for resources and also to check

the treatments with higher weed control efficiency.

### Materials and Methodology

The experiment was conducted during *rabi* season of 2019-20 at Research farm of Bihar Agricultural University, Sabour, Bhagalpur (Bihar). Geographically, Bhagalpur is situated at latitude of 25°15' 40" N and longitude 87°2' 42" E with altitude of 45.75 meters above the mean sea level under Gangetic plains of India. The average annual rainfall of this locality is 1167.0 mm, about 75 to 80% of which precipitates during middle of June to middle of October (about 120 days) and there is very scanty rainfall during the remaining period (245 days). Pre-monsoon showers are usually received in the month of May which is the hottest month when average monthly temperature reaches around 36°C while winter monthly average temperature drops below 10°C in the month of January. During crop season Nov.-April 2020, minimum and maximum temperature ranged between 5.5°C to 22.6°C and 17.3°C to 36.4 °C, respectively. While the mean relative humidity was in the ranges of 84.9% to 97.8% at 7:00 AM and 55% to 82.4 % at 2:00 PM respectively. Total rainfall received during crop growing season was 118.5 mm. The range of average sun shine hour and evaporation were 1.1 hr. to 8.9 hr. and 0.4 mm to 8.5 mm, respectively.

**Table 1:** Treatments used in research to control different types of weeds in lentil crop

Treatment	Herbicide name	Dose (g a.i. ha <sup>-1</sup> )	Time of application (DAS)
T <sub>1</sub>	Pendimethalin (30% EC)	1000	Pre-em (0-3 DAS)
T <sub>2</sub>	Oxyfluorfen (23.5% EC)	150	Pre-em (0-3DAS)
T <sub>3</sub>	Quizalofop ethyl (5% EC)	50	Post-em (25-30DAS)
T <sub>4</sub>	Topramezone (33.6% SC)	40	Post-em (25-30 DAS)
T <sub>5</sub>	Imazethapyr (10% SL)	60	Post-em (25-30 DAS)
T <sub>6</sub>	Propaquizafop (10% EC)	100	Post-em (25-30 DAS)
T <sub>7</sub>	Imazethapyr 35% + Imazamox 35% WG	60	Post-em (25-30DAS)
T <sub>8</sub>	Quizalofop ethyl (5% EC) + Imazethapyr (10% SL)	60+50	Post-em (25-30 DAS)
T <sub>9</sub>	Clodinafop-propargyl 8% + Na-acifluorfen 16.5% EC	60+50	Post-em (25-30 DAS)
T <sub>10</sub>	Pendimethalin (30% EC) fb Quizalofop ethyl (5% EC) + Imazethapyr (10% SL)	1000 fb 60+50	Pre fb Post-em (25-30 DAS)
T <sub>11</sub>	Oxyfluorfen (23.5% EC) fb Quizalofop ethyl(5% EC) + Imazethapyr (10% SL)	150 fb 60+50	Pre fb Post-em (25-30 DAS)
T <sub>12</sub>	Weed free	-	-
T <sub>13</sub>	Weedy check	-	-

Fertility status of the experiment as envisaged through organic carbon (0.52), available nitrogen (224.00 kg ha<sup>-1</sup>), phosphorus (39.20 kg ha<sup>-1</sup>) and potash (157.00 kg ha<sup>-1</sup>) were in available range. Thirteen weed management practices (Table 1) were implemented in a randomized complete block design (RCBD) with three replications. The size of the experimental plot was 966 m<sup>2</sup>. The variety used for sowing of lentil is HUL-57 with optimum seed rate 35 kg ha<sup>-1</sup> on 18<sup>th</sup> November, 2019. Seeds were sown at a depth 3-5 cm with spacing of 30cms about inter row spacing. The method of sowing adopted was line sowing opening the soil with furrow placed the seeds and covered with soil. The recommended dose of fertilizers is 20:40:00 N, P, K Kg ha<sup>-1</sup>, the source of N and P can be applied through urea and DAP. The fertilizer can be applied as basal application to all the treatment plots. The recommended cultural practices and plant protection measures were followed to raise the healthy crop. Harvesting is done by cutting the plant with sickle above the ground level after attaining the harvesting maturity and most of the pods became dry. In each and every treatment plot five plants were tagged, those plants harvested separately for record of post-harvest observations. Later net area was harvested, after harvesting the plants are allowed to sun dry in their respective plots. After sun drying, the plot wise produce was done through threshing, winnowing and cleaning operations manually,

followed by Weighing the produce as haulm yield and seed yield treatment wise in terms of kg plot<sup>-1</sup> and then converted into t ha<sup>-1</sup> (tone per ha). From both grain and straw yield harvest index (HI) was calculated. The number of weeds was recorded from three places selected at random in each plot by using quadrant of 50 cm x 50 cm size after that the samples were dried in a hot air oven at 70±2 °C for 48 hours or till a constant weight attained and then weed dry weight was recorded in gm<sup>-2</sup>. The five number of plants was selected at random in each plot to take crop growth parameters and yield attributes. The herbicides were sprayed with the help of a hand-operated Knapsack sprayer fitted with flat fan nozzle using 500 liters of water ha<sup>-1</sup>.

### Statistical Analysis

The data take down regarding different parameters in the present experiment were analysed statistically using OPSTAT Software for Randomized Complete Block Design. The standard error of means was determined in each item of study. The critical differences (C.D.) at 5% level of probability was worked out for comparing the treatment means, whenever, F test was considering significant. Data pertaining to weed density, biomass recorded at 30, 60, 90 DAS and harvest were subjected to square root transformation for statistical analysis.

The standard error of mean (SEm) was estimated with the formula:

$$SEm \pm = \sqrt{\frac{EMSS}{r}}$$

Where,

SEm $\pm$  = Standard error of mean

EMSS = Error mean sum of square

r = Number of replications on which the observation is based

$$CD \text{ at } 5\% = \sqrt{\frac{EV}{r}} \times 't' \text{ value for error d. f.}$$

Where,

CD = Critical difference

EV = Error variance

r = Number of replications on which the observation is based

t = t value from Fisher's table (1963) for error degree of freedom at 5% level of significance.

The data on weed density and weed biomass were analysed after square root transformation. The treatment comparisons were made at 5% level of significance.

## Results

### Grain yield, Straw yield and HI

Data on grain yield, straw yield and HI in lentil crop under

different herbicidal treatments was mentioned under Table 2. In this experiment, the results explored that Weed free treatment (Grain yield: 1.59 t/ha; Straw yield: 2.50 t/ha), pendimethalin fb quizalofop-ethyl + imazethapyr (Grain yield: 1.50 t/ha; Straw yield: 2.30 t/ha) and oxyflurofen fb quizalofop-ethyl + imazethapyr (Grain yield: 1.47 t/ha; Straw yield: 2.28 t/ha) recorded highest grain yield and haulm yield that has been statistically on par with each other and was slightly higher than the majority of weed control treatments. The lowest haulm yield (1.80 t/ha) and seed yield (1.00 t/ha) of lentil was noted under weedy check (T<sub>13</sub>) because of greater removal of available moisture and nutrients by the weeds and severe weed crop competition resulted into weak source and sink development along with retarded yield attributes and greater weed index. The data on harvest index (HI) under the influence of different weed control treatments in lentil showed that there was no significant impact of treatments for weed control on harvest index. However, maximum HI was recorded in T<sub>10</sub> (39.3%) treatment followed by the treatments T<sub>11</sub> (39.1%) and T<sub>12</sub> (38.9%). The treatments Weedy check (35.7%), imazethapyr + imazomox (36.2%) and Propaquizafop (35.8%) treated plots produced lower HI. Data related to densities and biomass of weeds which was affected by different herbicidal treatments in lentil crop are presented in Table 3.

At 60 DAS, the grass, sedge and broad leaved weed (blw) densities (no. m<sup>-2</sup>) was found minimum in weed free (T<sub>12</sub>) treatment (0.71) and it was significantly lower compared to all other treatments.

**Table 2:** Influence of different weed control treatments on grain yield (t ha<sup>-1</sup>), straw yield (t ha<sup>-1</sup>) and harvest Index (%) in lentil

S. No.	Treatments	Grain yield (t ha <sup>-1</sup> )	Straw yield (t ha <sup>-1</sup> )	Harvest index (%)
1	T <sub>1</sub>	1.27	2.14	37.4
2	T <sub>2</sub>	1.26	2.09	37.5
3	T <sub>3</sub>	1.13	1.94	36.8
4	T <sub>4</sub>	1.29	2.14	37.6
5	T <sub>5</sub>	1.23	2.03	37.6
6	T <sub>6</sub>	1.09	1.95	35.8
7	T <sub>7</sub>	1.04	1.83	36.2
8	T <sub>8</sub>	1.40	2.24	38.4
9	T <sub>9</sub>	1.35	2.16	38.5
10	T <sub>10</sub>	1.49	2.30	39.3
11	T <sub>11</sub>	1.47	2.28	39.1
12	T <sub>12</sub>	1.59	2.50	38.9
13	T <sub>13</sub>	1.00	1.80	35.7
SEm $\pm$		0.04	0.07	0.01
CD (P=0.05)		0.13	0.22	NS

Next to weed free treatment, the treatments namely T<sub>7</sub> (grass: 1.68; sedge: 4.18; blw: 3.29), T<sub>8</sub> (grass: 1.77; sedge: 4.18), T<sub>10</sub> (grass: 1.46; sedge: 4.10; blw: 3.02) and T<sub>11</sub> (grass: 1.57; sedge: 4.14; blw: 3.07) and T<sub>5</sub> (blw: 3.33) showed significantly lower respective weed counts per m<sup>2</sup> and these treatments were at par with weed free treatment. The highest weed density per m<sup>2</sup> at 60 DAS was recorded in weedy check treatment (grass: 4.95; sedge: 6.36; blw: 7.81) and was significantly high compared to all other treatments.

recorded in weedy check treatment (grass: 4.95; sedge: 6.36; blw: 7.81) and was significantly high compared to all other treatments.

At harvest, the grass, sedge and broad leaved weed densities (no. m<sup>-2</sup>) was found minimum in weed free (T<sub>12</sub>) treatment (0.71) and it was significantly lower compared to all other treatments. Next to weed free treatment, the treatments namely T<sub>7</sub> (grass: 2.19; sedge: 4.37; blw: 2.72), T<sub>8</sub> (sedge:

4.17), T<sub>10</sub> (grass: 1.77; sedge: 4.02; blw: 2.55) and T<sub>11</sub> (grass: 2.04; sedge: 4.05; blw: 2.67) and T<sub>9</sub> (sedge: 4.41) showed significantly lower respective weed counts per m<sup>2</sup> and these treatments were at

par with weed free treatment. The highest weed density per m<sup>2</sup> at harvest was recorded in weedy check treatment (grass: 6.01; sedge: 6.69; blw: 7.75) and was significantly high compared to all other treatments.

At 60DAS, the total weed biomass (g m<sup>-2</sup>) was found minimum in weed free (T<sub>12</sub>) treatment (0.71) and it was significantly lower compared to all other treatments. Next to weed free treatment, the treatments namely T<sub>7</sub> (3.49), T<sub>10</sub> (3.00) and T<sub>11</sub> (3.14) recorded significantly lower total weed biomass per m<sup>2</sup> and these treatments were at par with each other. The highest total weed biomass per m<sup>2</sup> at 60 DAS was recorded in weedy check treatment (8.72) and was significantly high compared to all other treatments.

At harvest, the total weed biomass ( $\text{g m}^{-2}$ ) was obtained minimum in weed free ( $T_{12}$ ) treatment (0.71) and it was significantly lower compared to all other treatments. Next to weed free treatment, the treatments namely  $T_{10}$  (6.19) and  $T_{11}$  (6.38) showed significantly lower total weed biomass per  $\text{m}^2$

and these treatments were at par with each other. The highest total weed biomass per  $\text{m}^2$  at time of harvest was recorded in weedy check treatment (14.09) and was significantly high compared to all other treatments.

**Table 3:** Influence of different weed control treatments on densities ( $\text{no. m}^{-2}$ ) of different types of weeds and total biomass ( $\text{g m}^{-2}$ ) of weeds at 60 DAS and at time of harvest in lentil

S. No.	Treatments	Density of grasses ( $\text{no. m}^{-2}$ )		Density of sedges ( $\text{no. m}^{-2}$ )		Density of broad leaved weeds ( $\text{no. m}^{-2}$ )		Biomass of weeds ( $\text{g m}^{-2}$ )	
		60 DAS	At Harvest	60 DAS	At Harvest	60 DAS	At Harvest	60 DAS	At Harvest
1	$T_1$	2.91 (8.00)	3.67 (13.00)	4.81 (22.70)	4.64 (21.10)	3.71 (13.33)	4.26 (17.67)	4.85 (23.03)	8.65 (74.50)
2	$T_2$	3.02 (8.67)	3.89 (14.67)	4.92 (23.70)	5.21 (26.70)	4.49 (19.67)	4.63 (21.00)	5.07 (25.25)	8.80 (77.07)
3	$T_3$	2.85 (7.67)	3.34 (10.67)	4.77 (22.30)	5.14 (26.00)	4.41 (19.00)	5.52 (30.00)	4.95 (24.04)	10.42 (108.08)
4	$T_4$	2.47 (5.67)	2.97 (8.33)	4.41 (19.00)	4.60 (20.70)	4.33 (18.33)	4.52 (20.00)	4.22 (17.38)	8.20 (66.77)
5	$T_5$	2.54 (6.00)	3.08 (9.00)	4.67 (21.30)	4.63 (21.00)	3.33 (10.67)	4.77 (22.33)	4.63 (21.01)	8.80 (76.97)
6	$T_6$	3.24 (10.00)	3.71 (13.33)	4.88 (23.30)	5.27 (27.30)	4.63 (21.00)	5.98 (35.33)	5.53 (30.14)	10.26 (104.91)
7	$T_7$	1.68 (2.33)	2.19 (4.33)	4.18 (17.00)	4.37 (18.70)	3.29 (10.33)	2.72 (7.00)	3.49 (11.75)	7.15 (50.75)
8	$T_8$	1.77 (2.67)	2.54 (6.00)	4.18 (17.00)	4.17 (17.00)	3.57 (12.33)	3.37 (11.00)	3.78 (13.83)	6.98 (48.36)
9	$T_9$	2.19 (4.33)	2.73 (7.00)	4.30 (18.00)	4.41 (19.00)	3.67 (13.00)	3.71 (13.33)	4.48 (19.65)	8.50 (71.86)
10	$T_{10}$	1.46 (1.67)	1.77 (2.67)	4.10 (16.30)	4.02 (15.70)	3.02 (8.67)	2.55 (6.00)	3.00 (8.61)	6.19 (37.84)
11	$T_{11}$	1.57 (2.00)	2.04 (3.67)	4.14 (16.70)	4.05 (16.00)	3.07 (9.00)	2.61 (6.33)	3.14 (9.38)	6.38 (40.22)
12	$T_{12}$	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)
13	$T_{13}$	4.95 (24.00)	6.01 (35.67)	6.36 (40.00)	6.69 (44.33)	7.81 (60.67)	7.95 (62.67)	8.72 (75.55)	14.09 (198.02)
SEm $\pm$		0.128	0.136	0.113	0.178	0.156	0.142	0.146	0.190
CD (P=0.05)		0.377	0.421	0.331	0.523	0.457	0.417	0.489	0.557

The figures in paranthesis are the original values\*\*\*\*

#### Weed control efficiency (%) and Weed index (%)

Data related to weed control efficiency (%) and weed index (%) which was affected by different herbicidal treatments in lentil crop are presented in Table 4. It was observed that the herbicidal activity i.e., weed control efficiency of herbicides was increased gradually and at time of harvest, there was slight declination was noticed in WCE. The weed control efficiency (%) was recorded maximum in weed free ( $T_{12}$ ) treatment (100%) at 60 DAS and at time of harvest and it was significantly higher compared to all other treatments. Next to weed free treatment, the treatments namely  $T_7$  (84.27% at 60 DAS),  $T_{10}$  (88.43% at 60 DAS and 80.93% at harvest) and  $T_{11}$  (87.49% at 60 DAS and 79.64% at harvest) showed higher

weed control efficiency (%) and these treatments were statistically at par with each other.

Weed index indicates percent reduction in grain yield due to crop-weed competition. So, the treatment with lesser weed index is considered to be more productive in nature. Among all the weed control treatments, weed free ( $T_{12}$ ) treatment produced zero weed index and the treatments  $T_8$  (11.92%),  $T_{10}$  (6.17%) and  $T_{11}$  (7.62%) produced significantly lower weed index and were statistically at par with each other. Weedy check (36.84%), propaquizofop (31.26%) and imazethpyr + imazamox (34.41%) were recorded significantly higher weed index and these treatments were statistically at par with each other.

**Table 4:** Influence of different weed control treatments on weed control efficiency (%) and weed index (%) in lentil

S. No.	Treatments	Weed Control Efficiency (%)		Weed Index (%)
		60 DAS	At Harvest	
1	$T_1$	69.51	62.42	19.62
2	$T_2$	66.30	60.99	20.78
3	$T_3$	67.98	45.31	28.54
4	$T_4$	76.84	66.28	18.74
5	$T_5$	71.99	61.05	22.66
6	$T_6$	59.86	47.02	31.26
7	$T_7$	84.27	74.30	34.41
8	$T_8$	81.74	75.50	11.92
9	$T_9$	73.75	63.59	14.68
10	$T_{10}$	88.43	80.93	6.17

11	T <sub>11</sub>	87.49	79.64	7.62
12	T <sub>12</sub>	100.00	100.00	0.00
13	T <sub>13</sub>	0.00	0.00	36.84
SEm ±		1.477	1.532	2.517
CD (P=0.05)		4.338	4.497	7.391

## Discussion

### Yield related parameters

Yield is the most significant and dynamic trait in crops. Yield is a measurement of the amount of a crop grown, or product such as grain, straw produced per unit land area. It reflects the interaction of the environment with all growth and developmental process that occur throughout the life cycle. Crop yield is directly and multiply determined by yield-component traits (such as branch number, pods per plant, seed weight and number of seeds per pod). Yield-related traits (such as biomass, harvest index, plant architecture, adaptation, resistance to biotic like weeds and abiotic constraints like different kinds of stresses) may also indirectly affect yield by affecting the yield-component traits or by other, unknown mechanisms (Shi *et al.*, 2009) [18]. The impact of weeds on agriculture crop plants was very high and they cause severe loss to farm productivity. Weeds reduce the crop growth; they invade crops, smother pastures and in some cases can harm livestock. They aggressively compete for water, nutrients and sunlight, resulting in reduced crop yield and poor crop quality. In this research, data on both straw and grain yields in lentil crop under various herbicide treatments showed that pre and post-emergence herbicides were sequentially applied at temporal variation will aid in weed reduction and yield increase throughout the critical stages of crop growth. Yield benefit due to different treatments of weed control to weedy check was largely attributed due to better yield attributes and co-operatively reduced density and dry matter of weeds with higher weed control efficiency. This was mainly due to minimizing the competition between weeds and crop throughout the growth phase of the crop, enables them for availing efficient utilization of available resources i.e. nutrients, light, moisture, and space that had much positive influence on growth, development and yield of chickpea (Singh *et al.* 2000) [19]. In this experiment, weed free treatment, pendimethalin *fb* quizalofop-ethyl + imazethapyr and oxyflurofen *fb* quizalofop-ethyl + imazethapyr recorded highest grain yield and haulm yield that has been statistically on par with each other and was slightly higher than the majority of weed control treatments. The lowest haulm yield (1.80 t/ha) and seed yield (1.00 t/ha) of lentil was noted under weedy check (T<sub>13</sub>) because of greater removal of available moisture and nutrients by the weeds and severe weed crop competition resulted into weak source and sink development along with retarded yield attributes and greater weed index. Kavaliauskaite and Bobinas (2006) [10], Adak (2006) [11], Brand *et al.* (2012) [7] and Stagnari and Pisante (2011) [21] also stated that crop-weed competition in lentil may decrease the yield and quality of produce which was a huge loss to farmers community. Minimum seed yield was noticed in plot accounted for 37.02 per cent of yield loss as evident by weed index value. This result was mainly due lower dry matter accumulation, LAI, height of plant, very poor development of yield characteristics and more weed index. And the treatments imazethapyr + imazomox (Grain yield: 1.04 t/ha; Straw yield: 1.83 t/ha), quizalofop-ethyl (Grain yield: 1.13 t/ha; Straw yield: 1.94 t/ha) and Propaquizafop (Grain yield: 1.09 t/ha; Straw yield: 1.95 t/ha) plots also produced significantly lesser seed yield and haulm yield and these treatments were

statistically comparable to weedy check (T<sub>13</sub>). Even though the weed control efficiency is high for imazethapyr + imazomox treatment, the production of yield was lower because of its phyto-toxicity (Punia *et al.*, 2015) [14]. The higher seed yield and haulm yield in said treatments might largely be attributed due to better yield attributes viz., more number of pods per plant, number of seeds pod<sup>-1</sup>, test weight. The increase in yield attributes was largely due to improved crop growth parameters viz., higher total dry matter accumulation and distribution in different parts of the plant and more LAI. Hence, the better growth and yield attributes was due to less weed crop competition, which favors the crop in utilization of moisture, nutrients, space and sunlight. The harvest index is an indicator of plant effectiveness in producing economic yield. It is defined as the ratio of grain yield to total above ground biomass. Since elevated weed population in the crop decreases, the seed and haulm yields were increased that result in higher HI. The data on harvest index (HI) under the influence of different weed control treatments in lentil showed that there was no significant impact of treatments for weed control on harvest index. However, maximum HI was recorded in T<sub>10</sub> (39.3%) treatment followed by the treatments T<sub>11</sub> (39.1%) and T<sub>12</sub> (38.9%). The treatments Weedy check (35.7%), imazethapyr + imazomox (36.2%) and Propaquizafop (35.8%) treated plots produced lower HI.

### Densities of different weeds and biomass

Weed density refers to the total number of weeds in an unit area as determined by counting or weighing. The dominant weeds found in experimental plot were *Vicia sativa* L, *Vicia hirsute* L, *Chenopodium album* L, *Anagallis arvensis* L, and *Solanum nigrum* are broad-leaved weeds. Grasses are *cynodon dactylon* L, *Dactyloctenium aegyptium* L, and *Phalaris minor* L. *Cyperus rotundus* are common sedges in lentil.

Data related to density of grasses, sedges and broad-leaved weeds (no. m<sup>-2</sup>) at various stages of growth i.e., 60 DAS and at time of harvest impacted by several weed control herbicidal treatments in lentil was recorded. It was observed that among herbicide treatments, at the stage of 60 DAS i.e., after application of post-emergence herbicides onwards, the plots treated with pendimethalin *fb* quizalofop-ethyl + imazethapyr (T<sub>10</sub>) and oxyflurofen *fb* quizalofop-ethyl + imazethapyr (T<sub>11</sub>) showed lower weed population irrespective of type of weed. Along with these two treatments T<sub>10</sub> and T<sub>11</sub>, the treatments namely quizalofop-ethyl + imazethapyr (T<sub>8</sub>) and imazethapyr + imazomox (T<sub>7</sub>) also showed lower weed population in all cases and were on par statistically with T<sub>10</sub> and T<sub>11</sub> treatments. The treatment quizalofop-ethyl + imazethapyr (T<sub>8</sub>) were on par statistically with T<sub>10</sub> and T<sub>11</sub> treatments in grasses and sedges but not in broad-leaved weeds. The treatment imazethapyr + imazomox (T<sub>7</sub>) also controlled weed population at its maximum level because of its phyto-toxic nature (Punia *et al.*, 2015) [14]. Significantly maximum weed density was noticed in weedy check at 60 DAS and during harvest and which was found far superior to the rest of the treatments at all development stages of the crop, whereas, weed free treatment recorded their lowest values. This result

was mainly due to luxuriant growth of all three types of weeds viz., grasses, broad leaved weeds and sedges which have made better use of available growth resources in former weedy treatment. Weed population was recorded as zero value in weed free treatment during entire period of crop growth among all the other treatments. Weed free plot indicated that complete control of weeds was only possible manually and culturally, however, it will neither be economical nor even possible in case of labour scarcity.

The weed biomass corresponds to number of weeds in most cases. The biomass of weeds increased with the age progression due to growth of weeds in girth, height, size and shape. At all the crop growth stages, weedy check results in significantly more weed biomass. This was mainly due to higher and persistent growth of weeds that allowed best use of growth resources. On the other hand, minimum weed biomass was noticed in weed free treatment recorded zero value over all other treatments during entire growth stages of crop. This may be due to removal of weeds by cultural methods at regular intervals, which resulted in reduced dry matter accumulation by weeds (Rajib *et al.*, 2014 and Chandrakar *et al.*, 2016) [15, 8]. All herbicide control plots limited the weed biomass significantly over weedy check primarily due to decline in weed number by herbicide application. Initially, the production of weed biomass ( $\text{g m}^{-2}$ ) was considerably few in pre-emergence herbicide treated plots. At further stages i.e., at 60 DAS and at harvest, the pre-emergence followed by post-emergence herbicides treated plots namely pendimethalin *fb* quizalofop-ethyl + imazethapyr & oxyflurofen *fb* quizalofop-ethyl + imazethapyr and post-emergence herbicide combination namely imazethapyr + imazomox treated plot attained lower weed dry weight compared to rest of the treatments. This is probably because of grassy weeds are highly susceptible to pendimethalin, oxyflurofen, imazethapyr and quizalofop-ethyl and broad-leaved weeds were killed by pendimethalin and sedge weeds were killed by imazethapyr having respective modes of actions. The treatment imazethapyr + imazomox also reduced the weed biomass significantly by killing the weeds with its phyto-toxicity. Upadhyay *et al.* (2012) [25] also states that the application of imazethapyr+imazomox (Odyssey + adjuvant @ 87.5 g + 1000 ml/ha) reduces the weed biomass over weedy check other herbicides at 40 DAS and at harvest in soybean. Prachand *et al.* (2015) [13] observed that application of imazethapyr 100 g/ha + quizalofop ethyl 75 g ha<sup>-1</sup> as POE in soybean lowers the weeds density and biomass which is at par with the imazethapyr + imazomox @ 80g/ha and imazethapyr+ imazomox @ 75g/ha as post emergence application.

#### Weed control efficiency (%) and weed index (%)

Weed control efficiency indicates percent reduction in weed dry weight by various weed control treatments over weedy check treatment. So, the one with highest weed control efficiency is considered to be the best treatment to control weeds. Performance of crop and yield of crop is positively correlated with weed control efficiency and weed index is negatively correlated with it. Data with respect to weed control efficiency (%) at different growth stages i.e., 60 DAS and at time of harvest in lentil as affected by different weed control herbicidal treatments showed that from the stage of application to pre-harvest stage, the herbicidal activity i.e., weed control efficiency of herbicides was increased gradually during time of harvest there was slight declination was noticed in WCE. From the time of application of post-

emergence herbicides, it was noticed that all the treatments pendimethalin *fb* quizalofop-ethyl + imazethapyr, oxyflurofen *fb* quizalofop-ethyl + imazethapyr and imazethapyr + imazomox showed significantly higher weed control efficiency over all other herbicide treatments in all growth stages of the lentil crop. The higher weed control efficiency was achieved in weed free treatment (100%), which can be explained by the fact physical weed control was more effective over other treatments, such as weed and propagating propagules like bulblets and bulbs in case of sedges, tap roots in broad-leaved weeds and stolon modifications in grasses etc., can be physically removed or uprooted by manual type weeding. Similar results was also noticed by Turk and Tawaha (2002) [24] who found that highest weed control efficiency in physical weeding in lentil, Baldev *et al.*, (2011) [3] in field pea and Khope *et al.*, (2011) [11] in chick pea. The higher weed control efficiency of weed free may also be clarified by the fact that no weed density was reported under this plot that regulated all kinds of weeds and helps in well established crop plants. These observations were in close proximity with findings of Upadhyay *et al.* (2012) [25] and Prachand *et al.* (2015) [13].

Weed index refers to the decrease in crop yields due to presence of weed in comparison to weed-free plots. So crop yield is negatively correlated with the weed control efficiency and weed density and biomass are positively correlated with weed indices. So, the treatment with lesser weed index is considered to be more productive in nature. Data related to weed index (%) which was affected by different herbicidal treatments in lentil crop showed that Among all the weed control treatments, weed free (T<sub>12</sub>) treatment produced zero weed index and the treatments pendimethalin *fb* quizalofop-ethyl + imazethapyr (6.17%), oxyflurofen *fb* quizalofop-ethyl + imazethapyr (7.62%) and quizalofop-ethyl + imazethapyr (11.92%) produced significantly lower weed index and these are statistically at par with each other. Weedy check (36.84%), propaquizofop (31.26%) and imazethapyr + imazomox (34.41%) were recorded significantly higher weed index and these on par statistically with each other. Weedy check recorded maximum weed index due to maximum weed growth during entire crop growth period and thereby resulted in severe weed competition by uncontrolled weed growth and thus resulted in maximum yield reduction. This finding is closer to the findings of Ahmad *et al.*, (1996) [2] and Tanveer and Ali (2003) [23] who reported that 20 to 30 percent loss in grain yield of lentil were quite usual and may increase up to 50 percent if the crop management practices are not properly followed. Rao *et al.*, (2010) [16] also reported 61 per cent yield reduction with uncontrolled weed growth in black gram. Apart from all these things, the treatment imazethapyr + imazomox (T<sub>7</sub>) showed higher weed control efficiency among all other treatments which means it can able to control the weeds and was significantly equals to weed free plot treatment. Even though it has maximum WCE, the yield due to this treatment was reduced which leads to increase in WI. This is probably due to phyto-toxic effect of this herbicide.

#### Conclusion

This study clearly indicates that weed free treatment (T<sub>12</sub>) produced significantly higher yields in lentil and the herbicide treatments namely pendimethalin *fb* quizalofop-ethyl + imazethapyr (T<sub>10</sub>) and oxyflurofen *fb* quizalofop-ethyl + imazethapyr (T<sub>11</sub>) also produced significantly maximum growth and yield parameters and were statistically at par with weed free treatment. weed dynamics of lentil under different

herbicide treatments conclude that the treatments pre-emergence followed by post-emergence herbicides treated plots namely pendimethalin fb quizalofop-ethyl + imazethapyr & oxyflurofen fb quizalofop-ethyl + imazethapyr and post-emergence herbicide combination namely imazethapyr + imazomox treated plot produced significantly lower weed parameters and control of all types of weeds and helps in well established crop plants. Finally, from the entire research it can be concluded that the application of pre-emergence followed by post-emergence herbicides is best way and economically feasible to farmers for getting better yields in lentil. The sequential use of pre and post emergence herbicides in temporal variation is a good option to control the weeds during critical crop growth stages in crop like lentil which highly susceptible to weeds for increasing the growth parameters and yield. By sequential application of pre and post emergence herbicides works effectively in reduction of weed density and biomass results in higher W.C.E, Which was at par with weed free treatment.

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