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Investigation on efficacy of pre and post emergence herbicides of chickpea (*Cicer arietinum*): Productivity, weed dynamics and economics

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Abstract
A field experiment was conducted during *rabi* season of 2019-20 at research farm of Bihar Agricultural University, Sabour, Bhagalpur to assess the effect of various pre and post-emergence herbicides in chickpea. The experiment consisted of 13 treatments *viz*. pendimethalin @ 1000 g a.i. ha^{-1} PE fb 1 HW, oxyfluorfen @ 100 g a.i. ha^{-1} PE fb 1 HW, imazethapyr @ 40 g a.i. ha^{-1} PoE, quizalofop-ethyl @ 50 g a.i. ha^{-1} PoE, topramezone @20 g a.i. ha^{-1} PoE, topramezone @25 g a.i. ha^{-1} PoE, clodinafop-propargyl + Na-acifluorfen @ 500 g a.i. ha^{-1} PoE, pendimethalin @ 1000 g a.i. ha^{-1} PE fb imazethapyr @ 40 g a.i. ha^{-1} PoE, pendimethalin @ 1000 g a.i. ha^{-1} PE fb quizalofop-ethyl @ 50 g a.i. ha^{-1} PoE, oxyfluorfen @ 100 g a.i. ha^{-1} PE fb imazethapyr @ 40 g a.i. ha^{-1} PoE, oxyfluorfen @ 100 g a.i. ha^{-1} PE fb quizalofop-ethyl @ 50 g a.i. ha^{-1} PoE apart from weedy check and weed free and followed a randomized block design with three replications. Out of the 13 treatment weed free recorded highest yield be it grain or straw which was statistically at par to treatments topramezone @ 25 g a.i. ha^{-1}, pendimethalin @ 1000 g a.i. ha^{-1} fb 1 HW, oxyfluorfen @ 100 g a.i. ha^{-1} fb 1 HW, topramezone @ 20 g a.i. ha^{-1}. Weed density and biomass were found significantly lower in weed free treatment which was statistically at par to pendimethalin @ 1000 g a.i. ha^{-1} fb 1 HW, oxyfluorfen @ 100 g a.i. ha^{-1} fb 1 HW, topramezone @ 25 g a.i. ha^{-1}, topramezone @ 20 g a.i. ha^{-1}. The highest net return and benefit cost ratio was recorded under topramezone @ 25 g a.i. ha^{-1} which was statistically at par to topramezone @ 20 g a.i. ha^{-1}, pendimethalin @ 1000 g a.i. ha^{-1} fb quizalofop-ethyl @ 50 g a.i. ha^{-1} and pendimethalin @ 1000 g a.i. ha^{-1} fb 1 HW, oxyfluorfen @ 100 g a.i. ha^{-1} fb 1 HW, Oxyfluorfen @ 100 g a.i. ha^{-1} at 1DAS fb Imazethapyr @ 40 g a.i. ha^{-1} and Oxyfluorfen @ 100 g a.i. ha^{-1} at 1DAS fb quizalofop-ethyl @ 50 g a.i. ha^{-1} at 25DAS. Hence, it can be concluded that application of topramezone @ 25 g a.i. ha^{-1}, topramezone @ 20 g a.i. ha^{-1}, pendimethalin @ 1000 g a.i. ha^{-1} fb 1 HW and oxyfluorfen @ 100 g a.i. ha^{-1} fb 1 HW are equally effective with higher benefit cost ratio where labour is scarce.

Keywords: Weed management, chickpea, economics, herbicide

Introduction
Chickpea (*Cicer arietinum* L.) is an old self-pollinated legume that is thought to have arisen in south-eastern Turkey and a portion of Syria. In contrast to other pulses, chickpea is a great source of carbohydrates and protein, accounting for approximately 80% of total dry seed mass. Chickpeas are low in cholesterol and high in dietary fiber (DF), vitamins, and minerals. It is abundant in unsaturated fatty acids and fiber, as well as proteins and minerals (Williams and Singh 1987) [1]. It contains more carotenoids, such as β-carotene, than genetically modified 'golden rice' and has no anti-nutritional causes (Mallikarjuna *et al*. 2007) [2]. Chickpea are often eaten as a seed food in various ways around the world, with preparations influenced by ethnic and regional influences. Chickpeas are broken (cotyledons) and ground to make flour (besan) in the Indian subcontinent, which is used to make various snacks.

It is one of the most important food legume plants in sustainable agriculture systems due to its low production expense, broader adaptability, ability to fix atmospheric nitrogen and work in different crop rotations, and existence of a prolific tap root system. Chickpea, by its symbiotic relationship with rhizobium, can fix up to 140 kg/ha of atmospheric nitrogen and meets its 80 percent requirement. It also contributes to the improvement of soil quality for subsequent cereal crop production by incorporating organic matter for the preservation of soil health and ecosystem.

Though global production and yield of chickpea have not raised significantly in recent decades, the world's population has been continuously increasing.

As a result, the net availability of chickpea per capita has decreased. There is a significant difference in possible yield and farm output. Inappropriate production methods, such as weed control, insufficient biological nitrogen fixation, seed damage from a variety of pathogens and pests, and cultivar vulnerability to abiotic stresses, are major contributors of less production. Out of all these factors, weeds are the major causes of low production of gram as unrestricted weed growth can reduce the yield up to 31.33%. (Kachhadiya, 2009) [3].

Singh and Singh (1982) [4] discovered that weed-free conditions maintained for the first 60 days produced results comparable to a completely weed-free treatment. Several studies have shown that successful weed control can lead to an improvement in chickpea yield increased by 17–105 percent. Mainly manual weeding has been employed to control weed in chickpea, but on the other hand, it is proving difficult due to labor shortages at crucial weeding times and rising costs. So, there is need to look for other alternatives and one such alternative is use of herbicides. Several herbicides are being successfully used in other pulse crop. Considering the importance of efficient weed management methods, this study sought to identify the best weed control practices for increasing chickpea yields by employing 13 herbicidal combinations to minimize crop-weed competition for resources and to identify treatments with higher weed control efficiency.

Methodology

During the *rabi* season of 2020-2021, a field experiment was conducted at the Bihar Agricultural University's Sabour research farm in Bhagalpur, Bihar, to evaluate the efficacy of several pre and post-emergence herbicides in chickpea. On November 9, 2020, chickpea cv. GCP-105 was sown with a seed rate of (80 kg ha^{-1}) and spacing of (30cm x 10 cm). The crop was fertilized evenly with 20:40:00 kg N: P_2O_5: K_2O ha^{-1}, with the whole N and P_2O_5 dose administered as a basal. The experiment comprised of 13 treatments mentioned in table 1. The experiment followed a randomized block design with three replications. The climate was more or less favourable to the growth of chickpea, with minimum and maximum temperatures for the crop season ranging from 7.7°C to 23°C and 18.8°C to 35°C, respectively. The initial soil pH, EC, organic carbon registered before the experiments began was 7.51, 0.12 $dSm^{-1}$and 0.51% respectively. Nutrients like nitrogen (219.88 kg ha^{-1}), phosphorus (35.46 kg ha^{-1}) and potash (149.8 kg ha^{-1}) were in available range.

A 1 × 1 m size quadrate was used to collect data on weed density, weed dry weight, and weed control efficiency at 30, 60, and 90 days after sowing, as well as at harvest. Weed control efficiency was calculated using the Mani *et al*. (1973) [5] methodology based on weed dry matter. The normality of distribution was not observed in the context of weed observations. As a result, before statistical analysis, the data were subjected to square root transformation to normalize the distribution. Data on grain yield, straw yield, and harvest index were recorded. Economic analysis of data was also done using the cost of inputs and selling price of produce obtained after processing of harvested material. The F-test approach was used to statistically examine all of the data. To establish the significance of differences between treatment means, critical difference values of P=0.05 were frequently utilized.

Results and Discussion

Yield

Data revealed that the grain yield of chickpea was significantly influenced by several weed control treatments. Among several weed control treatments highest grain yield (1.80 t ha^{-1}) was found in weed free treatment which was statistically at par to treatments T_8 (1.74 t ha^{-1}), T_3 (1.73 t ha^{-1}), T_4 (1.67 t ha^{-1}), T_7 (1.66 t ha^{-1}) and superior over rest of the treatments. Lowest grain yield was obtained under weedy check (0.98 t ha^{-1}) (table 2).

Highest haulm yield was obtained under weed free treatment (2.24 t ha^{-1}) which was statistically at par to all other treatments except weedy check, T_5, T_6 and T_9. Lowest haulm yield (1.37 t ha^{-1}) was produced under weedy check followed by T_9 (1.62 t ha^{-1}), followed by T_5 (1.88 t ha^{-1}) followed by T_6 (1.91 t ha^{-1}).

It was observed that, there was no significant effect of weed control treatments on harvest index. However, maximum HI (44.51%) was recorded in T_2 (weed free) closely followed by treatment T_8 (44.27%).

The improved grain yield and haulm yield in these treatments attributed by better interception of sunlight, soil nutrient and space by the crop due to lower weed density and higher WCE, as well as better yield attributes. The yield advantage of various weed control treatments over weedy control was largely attributed to improved yield attributes and cooperatively decreased weed density and weed dry biomass with higher WCE. Butter *et al*. (2008) [6], Sharma (1999), Kumar *et al*. (2011) [8], Patel *et al*. (2006) [9] and Chaudhary *et al*. (2011) have indeed reached similar conclusions.

Weed control efficiency

WCE is indicate that how well weed controlled by the herbicide by reducing weed population or dry weight over weedy plot in treated plot. At 60 DAS, the weed control efficiency (%) (Table 4) was recorded maximum in weed free (T_2) treatment (100%) and it was significantly higher compared to all other treatments. Among herbicide treatment T_3 (88.63) showed maximum weed control efficiency total weed biomass per m^2 and was statistically at par to T_4 (87.45) and T_8 (86.65). At harvest, the weed control efficiency (%) was recorded maximum in weed free (T_2) treatment (96.97%) and it was significantly higher compared to all other treatments. Among herbicide treatment T_3 (81.29) showed maximum weed control efficiency total weed biomass per m^2 and was statistically at par to T_4 (80.52) and T_8. The weed free method attained the highest WCE, which can be clarified by the fact that physical weed control was more successful than other treatments, such as weed and propagating propagules can be eliminated or uprooted manually. These findings are consistent to the findings of Buttar *et al*. (2008) [6], Kachhadiya *et al*. (2009) [3] and Gupta *et al*. (2012) [11].

Table 1: Treatments used in research to control different types of weeds in chickpea

S. No.	Treatments	Rate of application (g a.i./ha)	Time of application
T_1	Weedy check		
T_2	Weed free		Up to 60 days
T_3	Pendimethalin *fb* 1 HW	1000	PE (1 DAS) *fb* 1 HW (30 DAS)

T_4	Oxyfluorfen *fb* 1 HW	100	PE (1 DAS) *fb* 1 HW (30 DAS)
T_5	Imazethapyr	40	25 DAS (PoE)
T_6	Quizalofop-ethyl	50	25 DAS (PoE)
T_7	Topramezone	20	25 DAS (PoE)
T_8	Topramezone	25	25 DAS (PoE)
T_9	Clodinafop-propargyl + Na-acifluorfen	500	25 DAS (PoE)
T_{10}	Pendimethalin *fb* imazethapyr	1000 g *fb* 40	PE (1 DAS) *fb* PoE (25 DAS)
T_{11}	Pendimethalin *fb* quizalofop-ethyl	1000 g *fb* 50	PE (1 DAS) *fb* PoE (25 DAS)
T_{12}	Oxyfluorfen *fb* imazethapyr	100 g *fb* 40	PE (1 DAS) *fb* PoE (25 DAS)
T_{13}	Oxyfluorfen *fb* quizalofop-ethyl	100 g *fb*50	PE (1 DAS) *fb* PoE (25 DAS)

Table 2: Influence of different weed control treatments on grain yield (t ha^{-1}), haulm yield (t ha^{-1}), harvest index (%) and economics of chickpea

S. No.	Grain yield (t ha^{-1})	Haulm yield (t ha^{-1})	HI (%)	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T_1	0.98	1.37	41.79	57948	33558	1.38
T_2	1.80	2.24	44.51	105161	69675	1.96
T_3	1.73	2.23	43.59	101415	69826	2.21
T_4	1.67	2.22	42.98	98471	67439	2.17
T_5	1.31	1.88	41.07	78028	52294	2.03
T_6	1.33	1.91	41.03	79335	52561	1.96
T_7	1.66	2.16	43.45	97653	69306	2.44
T_8	1.74	2.19	44.27	101754	72564	2.49
T_9	1.22	1.62	43.15	72010	39836	1.24
T_{10}	1.41	2.00	41.21	83714	56331	2.06
T_{11}	1.58	2.15	42.22	93282	64859	2.28
T_{12}	1.44	2.03	41.62	85837	58499	2.14
T_{13}	1.50	2.06	42.11	88858	60480	2.13
SEM ±	0.07	0.09	1.01	3898	3898	0.13
CD (P=0.05)	0.20	0.26	-	11378	11378	0.39

Table 3: Influence of different weed control treatments on density of total weeds (No. m^{-2}) and dry weight of total weeds (g m^{-2}) in chickpea

S. No.	Total weed density (No. m^{-2})				Dry weight of total weeds (g m^{-2})			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
T_1	8.95 (79.67)	11.47 (131.33)	12.70 (160.83)	11.51 (132.00)	2.27 (4.67)	8.73 (75.67)	13.56 (183.47)	14.08 (197.67)
T_2	0.71 (0.00)	0.71 (0.00)	3.93 (15.00)	3.34 (10.67)	0.71 (0.00)	0.71 (0.00)	2.33 (4.91)	2.55 (6.00)
T_3	5.55 (30.33)	4.91 (23.67)	5.67 (31.67)	5.02 (24.67)	1.34 (1.33)	3.01 (8.58)	5.60 (30.83)	6.12 (37.00)
T_4	5.84 (33.67)	5.30 (27.67)	6.45 (41.33)	5.87 (34.00)	1.41 (1.50)	3.16 (9.50)	5.63 (31.17)	6.24 (38.50)
T_5	8.27 (68.00)	6.89 (47.00)	8.19 (66.67)	7.56 (56.67)	1.90 (3.11)	5.00 (24.50)	9.39 (87.67)	9.86 (96.67)
T_6	8.45 (71.00)	7.49 (55.67)	8.65 (74.33)	8.20 (66.67)	1.95 (3.33)	5.11 (25.67)	9.68 (93.15)	10.42 (108.00)
T_7	8.57 (73.00)	5.46 (29.33)	6.72 (44.67)	6.10 (36.67)	2.04 (3.67)	3.48 (11.67)	5.93 (34.67)	6.47 (41.33)
T_8	8.37 (69.67)	5.31 (27.67)	6.36 (40.00)	5.55 (30.33)	1.90 (3.13)	3.36 (10.83)	5.76 (32.66)	6.31 (39.37)
T_9	8.46 (71.00)	6.39 (40.33)	7.27 (52.67)	6.31 (39.33)	2.00 (3.50)	4.42 (19.17)	9.17 (83.61)	9.70 (93.67)
T_{10}	5.93 (34.67)	6.14 (37.33)	7.43 (54.67)	6.89 (47.33)	1.39 (1.44)	3.58 (12.33)	7.24 (52.00)	8.03 (64.00)
T_{11}	6.12 (37.00)	6.26 (38.67)	7.63 (57.67)	7.36 (53.67)	1.51 (1.80)	3.81 (14.00)	7.66 (58.33)	8.30 (68.33)
T_{12}	5.95 (35.00)	6.04 (36.00)	7.45 (55.00)	6.94 (47.67)	1.45 (1.60)	3.62 (12.67)	7.49 (55.67)	7.63 (57.67)
T_{13}	6.26 (38.67)	6.31 (39.33)	7.78 (60.00)	7.20 (51.33)	1.42 (1.52)	3.85 (14.33)	8.05 (64.33)	8.69 (75.00)
SEM ±	0.15	0.15	0.18	0.16	0.07	0.11	0.10	0.06
CD (P=0.05)	0.44	0.43	0.52	0.46	0.22	0.32	0.28	0.16

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

S. No.	Weed Control Efficiency (%)		Weed index (%)
	60 DAS	At Harvest	
T_1	0.00	0.00	45.51
T_2	100.0	96.97	0.00
T_3	88.63	81.29	4.11
T_4	87.45	80.52	6.60
T_5	67.61	51.08	27.05
T_6	66.02	45.36	26.07
T_7	84.62	79.09	7.30
T_8	85.65	80.08	3.35
T_9	74.56	52.60	31.78
T_{10}	83.73	67.62	21.52
T_{11}	81.50	65.43	12.45
T_{12}	83.19	70.82	19.50
T_{13}	81.04	62.05	16.25

SEM ±	1.16	0.46	3.83
CD (P=0.05)	3.38	1.33	11.19

Weed index (WI)

WI indicates how efficiently weed were controlled which reflect in term of yield. Among all the weed control treatments, weed free (T_2) treatment produced zero weed index (WI) and the treatments T_8 (3.35), T_3 (4.11), T_4 (6.60) and T_7 (7.30) produced significantly lower WI and were also statistically at par with each other. Minimum weed index (45.51) was found under weedy check (T_1) followed by clodinafop-propargyl + Na-acifluorfen @ 500 g a.i. ha^{-1} (31.78). Weedy check registered the highest weed index due to the highest weed growth over the entire crop growth cycle, resulting in extreme weed competition by unregulated growth of weeds and the highest reduction in yield.

Total weed density

Total weed density consists of grasses, sedges and broad leaves collected per meter square area which shows overall view of abondance of weeds in the crop field. At 30 DAS, among weed control treatments, weed free treatment recorded significantly minimum total weed density per m^2 (0.71) whereas weedy plot exhibited maximum total weed density per m^2 (8.95) (table 3). Among herbicide treatments, minimum total weed density per m^2 (5.55) was recorded under T_3 which was at par to T_4 (5.84), T_{10} (5.93), and T_{12} (5.95). At 60 DAS, among weed control treatments, weed free treatment recorded significantly minimum total weed density per m^2 (0.71) whereas weedy plot exhibited maximum total weed density per m^2 (11.47). Among herbicide treatments, minimum weed population per m^2 (4.91) was recorded with T_3 which was at par to T_4 (5.30) and T_8 (5.31) and was found significantly lower than rest of the treatments. At 90 DAS, among weed control treatments, weed free treatment recorded significantly minimum total weed density per m^2 (3.93) whereas weedy plot exhibited maximum total weed density per m^2 (12.70). Among herbicide treatments, minimum weed population per m^2 (5.67) was recorded with T_3 followed by T_4 (6.45), T_7 (6.72) and T_8 (6.36) which were at par to each other and found significantly lower than rest of the treatments. At harvest, among weed control treatments, weed free treatment recorded significantly minimum total weed density per m^2 (3.34) whereas weedy plot exhibited maximum total weed density per m^2 (11.51). Among herbicide treatments, minimum weed population per m^2 (5.02) was recorded with T_3 followed by T_4 (5.87), T_8 (5.55) and T_9 (6.31) which were at par to each other and found significantly lower than rest.

Total weed biomass

At 60 DAS, the total weed biomass (g m^{-2}) (table 3) was recorded significantly minimum in weed free (T_1) treatment (0.71) compared to all other treatments. Among herbicide treatment T_3 (3.01) and T_4 (3.16) showed minimum total weed biomass per m^2 and were at par to each other followed by T_7 (3.48), T_8 (3.36), T_{10} (3.58) and T_{12} (3.62). The significantly highest total weed biomass per m^2 at 30 DAS was recorded in weedy check treatment (8.73) as compared to all other treatments. At harvest, the total weed biomass (g m^{-2}) was recorded significantly minimum in weed free (T_1) treatment (2.55) compared to all other treatments. Among herbicide treatment T_3 (6.12) and T_4 (6.24) showed minimum total weed biomass per m^2 followed by T_7 (6.47) and T_8 (6.31). The significantly highest total weed biomass per m^2 at 30 DAS was recorded in weedy check treatment (14.08) as compared to all other treatments. Considerably higher weed density noticed throughout crop duration in weedy check, whereas the weed free treatment had the lowest values than other control measures. Similar findings were also obtained by Nepali *et al*. (2020) and Jangade *et al*. (2019) [12, 13]. It was mostly owing to the robust development of broad-leaved weeds, grasses, and sedges which has resulted in better use of available growth resources in former weedy treatment.

Economics

Reflection of management of weed can be seen in yield but finely how cost effectively weed managed, this can be observed only in economics of production system of the crop. The highest gross return of ₹ 105161 ha^{-1} was recorded under weed free treatment (T_2) which was statistically at par to topramezone @ 25 g a.i. ha^{-1} (₹ 101754 ha^{-1}), pendimethalin @ 1000 g a.i. ha^{-1} fb 1 HW (₹ 101415 ha^{-1}), oxyfluorfen @ 100 g a.i. ha^{-1} fb 1 HW (₹ 98471 ha^{-1}) and topramezone @ 20 g a.i. ha^{-1} (₹ 97653 ha^{-1}). Lowest gross return was obtained under weedy check (₹ 57948 ha^{-1}). The highest net return of ₹ 72564 ha^{-1} was recorded under topramezone @ 25 g a.i. ha^{-1} which was statistically at par to pendimethalin @ 1000 g a.i. ha^{-1} fb 1 HW (₹ 69826 ha^{-1}), topramezone @ 20 g a.i. ha^{-1} (₹ 69306 ha^{-1}), oxyfluorfen @ 100 g a.i. ha^{-1} fb 1 HW (₹ 67439 ha^{-1}), pendimethalin @ 1000 g a.i. ha^{-1} fb quizalofop-ethyl @ 50 g a.i. ha^{-1} (₹ 64859 ha^{-1}) and weed free (₹ 69675 ha^{-1}). Lowest net return was obtained under weedy check (₹ 33558 ha^{-1}). This was mostly owing to greater gross returns recorded in these treatments as a result of greater chickpea economic yield. Similar reports were also published by Sharma *et al*. (2006) [9], Kachhadiya *et al*. (2009) [3], Sharma and Goswami (2010) [15], Kaushik *et al*. (2014) [16] and Kumar *et al*. (2020) [17]. Data revealed that effect of different weed control treatments was found significant on benefit: cost ratio. Highest benefit: cost ratio (2.49) was found under topramezone @ 25 g a.i. ha^{-1} which was statistically at par to topramezone @ 20 g a.i. ha^{-1} (2.44), pendimethalin @ 1000 g a.i. ha^{-1} fb 1 HW (2.21), oxyfluorfen @ 100 g a.i. ha^{-1} fb 1 HW (2.17), Pendimethalin @ 1000 g a.i. ha^{-1} fb quizalofop-ethyl @ 50 g a.i. ha^{-1} (2.28), oxyfluorfen @ 100 g a.i. ha^{-1} fb Imezathapyr (2.14), oxyfluorfen@100 g a.i. ha^{-1} fb quizalofop-ethyl (2.13). Lowest benefit: cost ratio (1.38) was found under weedy check. followed by clodinafop-propargyl + Na-acifluorfen @ 500 g a.i. ha^{-1}. This was largely due to higher phyto-toxicity of clodinafop-propargyl + Na-acifluorfen @ 500 g a.i. ha^{-1} reduces the plant population in weeding operations thus attained low economic yield. Kakade *et al*. (2020) [14] also reached the same conclusion.

Conclusion

Based on the field trial findings, it is rational to assume that potential output, and effective weed control in chickpea may be reached by maintaining weed free conditions by maintaining weed free condition throughout crop growing phase, where labor is readily accessible but economically this treatment is not feasible to the farmers because of having less benefit cost ratio. Whereas, another alternative like application of topramezone @ 25 g a.i. ha^{-1} is equally effective with higher benefit cost ratio as well as higher yield attributes.

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