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RESEARCH ARTICLE

Encapsulated herbicide in preceding rice on weed growth and blackgram productivity in rice-okra-blackgram cropping system under tropical conditions

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ABSTRACT

Weeds in the double cropping of rice are different from the rice-vegetable-pulse cropping system as there will be a shift in weed flora due to changes in the cropping system. Field experiments were conducted during the summer season of 2017 and 2018 to study the residual effect of encapsulated/loaded herbicide applied in preceding rice on weed control and productivity of black gram under the rice-okra-blackgram cropping system. The experiment consists of eight weed control treatments, *viz.* encapsulation of herbicide with zeolite, biochar, starch, water-soluble polymer, commercial formulation of herbicides, weed-free and weedy check of preceding rice and okra. However, the residual crop of black gram was sown without disturbing the layout of the preceding experiment. The residual effect of encapsulated herbicides expressed significant exerted difference in weed density and dry weight at 40 DAS, in both the years. Irrespective of weed control treatments, the residual effects of oxadiargyl-loaded biochar resulted in a 55.0% and 61.3% reduction in grass weed density and a 50.4% and 65.0% reduction in grass weed dry weight in 2017 and 2018, respectively when compared to the weedy control, which was comparable to all other herbicidal residual effects in blackgram. However, the residual impact of encapsulated/loaded herbicides did not significantly influence blackgram seed germination. Whereas, significantly higher clusters/plant (4.8, 7.2%) with high seeds/plant (20.0, 26.2%) and seed yield (108,101 kg) was recorded under oxadiargyl-loaded biochar compared to oxadiargyl loaded zeolite during 2017 and 2018, respectively. It can be concluded that the oxadiargyl-loaded biochar and zeolite releases active ingredients for a longer time which reduces the growth of later emerging weeds and the build-up of soil weed seed banks in succeeding crops.

Keywords: Biochar, Encapsulated/loaded herbicide, Oxadiargyl, Herbicide residue, Weed control efficiency, Zeolite

INTRODUCTION

Blackgram (*Vigna mungo* L.) is one of the important pulse crops grown throughout tropical regions and is able to resist adverse climatic conditions. It is one of the most essential constituents of the Indian diet and supplies a major part of the protein requirement to the vegetarian population. Pulse crops are an integral part of the cropping system because they fit well within the crop rotation and maintain soil fertility through biological nitrogen fixation. India is the leading producer and consumer of pulses crops, with 25 and 27% of the world's acreage and production, respectively (Pankaj *et al.* 2020). The productivity of blackgram is declining yearly due to biotic and abiotic factors. Among the biotic factors, weeds reduce crop yields substantially compared to pests and diseases, with its inhibitory effect on crop growth and productivity. Weeds compete with crops during the early period of 20-40 days is very critical, and season-long weed competition has been found to reduce blackgram yield to the extent of 87% depending upon the type and intensity of weed flora (Yadav *et al.* 2015, Upasani *et al.* 2017). Weeds survive and produce more seeds contributing to the weed seed bank from which weed seedlings are recruited in succeeding crops. Adopting crop rotation and alternating herbicide selection could alter weed seed bank in soil. In the present agricultural scenario, farmers mostly prefer chemical methods of weed control because of its excellent efficacy, quick results, low cost, and ease of application in larger areas. Meanwhile, continuous and indiscriminate use of the same herbicide in the same field causes soil degradation and pollutes water bodies, aquatic flora, and fauna. Suzer

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and Byuk (2010) reported that soil persistence of imazethapyr+ imazamox causes residual toxicity in succeeding crops of sugar beet and rape seed. In contrast, maize, winter wheat and barley were non-susceptible to the residue of imazamox. Janaki *et al.* (2014) reported that the influence of clay and organic matter on herbicide sorption and observed that persistence of pyrazosulfuron-ethyl depends on the clay and organic matter content of soils. Janaki *et al.* (2015) reported that few sulfonylurea herbicide residues in soil can affect rational crops even at lower concentrations. Herbicide residue persists relatively long, placing succeeding sensitive crops at risk. Janaki *et al.* (2017) reported that oxyfluorfen persists in soil and contaminates aquatic surroundings through leaching and runoff, a highly persistent and toxic herbicide. Zahana *et al.* (2018); Shamim *et al.* (2020), Bommayasamy and Chinnamuthu (2021) found that herbicides used for weed control in soil or foliar application may be expected to control weeds within the season. At the same time, herbicides are expected to persist in soil and have a residual effect on succeeding crop growth (Paul *et al.* 2022). Because of the above facts, the present investigation was carried out to study the residual effect of encapsulated/loaded herbicide applied in preceding rice crop on weed control and productivity of blackgram, under rice-okra-blackgram cropping system in tropical conditions.

MATERIALS AND METHODS

Experimental details and design

Field experiments were conducted during the summer season of 2017 and 2018 at Agricultural College and Research Institute, Madurai and Central Island Agricultural Research Institute, Port Blair, to study the residual effect of encapsulated/loaded herbicide applied in preceding rice crop on weed control efficacy and productivity of blackgram, under rice-okra-blackgram cropping system. The field experiment was laid out in a randomized block design and replicated thrice. The field experiment consisted of eight weed control treatments of preceding rice, *viz.* oxadiargyl loaded biochar, oxadiargyl loaded zeolite, oxadiargyl encapsulated starch, oxadiargyl encapsulated water-soluble polymer, oxadiargyl at 100 g/ha, butachlor at 1.25 kg/ha *fb* hand weeding (HW) at 40 DAT, weed free check and weedy check. Succeeding crops were sown without disturbing the layout of the experimental field of preceding rice, and recommended packages of practices were followed to raise the crops. T_1 to T_5: No weed control treatment is applied, and observing the residual effects of herbicides from the rice crop on the succeeding crops (okra and blackgram) helps assess how long the herbicide persists in the soil and whether it impacts weed growth or crop performance (two hand weeding at 20 and 40 DAS) involves manual weed removal at two critical crop stages and ensures that the crops are kept free from weeds. Comparing the untreated groups will help evaluate the effect of manual weed control versus the residual herbicide effect. T_7 (Weed-free check): This treatment keeps the plot free from weeds throughout the growing period, comparing how well the crops perform under ideal conditions versus with residual herbicide effects or without weed control. In T_1 to T_5 and T_8-weedy check, no treatment was imposed whereas, in succeeding okra and blackgram weed control treatment was imposed in two hand weeding at 20 and 40 DAS and weed free check. After the harvesting of okra, the experimental field was sprayed with glyphosate at 1.0 kg/ha for keeping the field clean before the next crop is sown. After seven days, blackgram variety VBN (Bg)-8 seeds were sown with 30 x 10 cm spacing during the first week of May 2017 and the fourth week of March 2018 and harvested in the third week of July 2017 and June 2018. The recommended dose of 100% NPK (25:50:25 kg of NPK per ha) was applied as basal in the form of urea, diammonium phosphate and muriate of potash. Pest and disease incidence was not observed during the growing season. All the other recommended agronomic and plant protection measures adopted to raise the crop were taken as need based. Germination of black gram was recorded by counting the number of hills germinated in each plot, ten days after sowing and expressed as a percentage over total hills sown. The height of the plant was measured from the bottom of the plant to the tip of the growing point at the harvest stage of the crop and expressed in centimeters. Blackgram seed yield from each net plot was cleaned and sun-dried to reduce moisture content by up to 9% and weighted seed yields were expressed in kg/ha.

Growth analysis is helpful for crop physiologists and agronomists interested in understanding the differential behaviour of crop varieties under complex environmental conditions and concerning various treatments. Some of the essential components of growth analysis, *viz*. leaf area index, crop growth rate and relative growth rate, were carried out. The leaf area (LA) was worked out using the formula suggested by Mc Kee (1964).

Where LAI is the leaf area index, L is the length of the leaf from the top (cm), W is the maximum width of the leaf blade (cm), and the number of leaves per plant.

Crop Growth Rate (CGR) is a critical measure of how efficiently a crop produces biomass over time. It quantifies the rate of biomass accumulation in the crop on a per-unit-area basis over a specified time period. The unit of measurement is grams per meter square per day (g/m²/day), which helps assess how much dry matter the crop produces each day per unit area. Crop Growth Rates were computed at 50 DAS to harvest stage and expressed in g/m^2/day.

Where W1 and W2 are plant weights recorded at t1 and t2 days, respectively, t2 - t1 is the time interval in days, and G is the ground area in which W1 and W2 were estimated. Relative Growth Rate (RGR) is the rate of dry weight increase per unit weight that is already present per unit time.

Where**,** W1 and W2 whole plant dry weight at t1 and t2 days, respectively, expressed as g/g/day.

Weed density and dry weight

Species-wise weed density was observed in the weedy check using 0.5m x 0.5m quadrat in randomly fixed places in the treatments of each plot at 40 DAS. Weeds falling within the quadrat frame were counted and recorded species-wise weed density, expressed in numbers/m^2. The same weeds were dried in a hot air oven for 72 hrs at 80°C, and dry weight was expressed in g/m^2.

Statistical analysis

Data on weed density and dry weight showed high variation; hence, they were subjected to transformation and analysed. Observed data of crops and weeds subjected to statistical scrutiny ANOVA (Analysis of Variance) as per methods suggested by Gomez and Gomez (1984). Whenever a significant difference existed, the least significant difference (LSD) was constructed at 5% probability level. Such treatments where the differences were not significant were denoted as NS.

RESULTS AND DISCUSSION

Weed density and dry weight of grass weeds

The residual effect of encapsulated/loaded herbicide significantly exerted the difference in grasses, sedges, broad-leaved weed density, and weed dry weight at 40 DAS in both years of crop growth (**Table 1**). Weed-free check recorded distinctly low weed density and dry weight of grasses, sedges, and BLW. This was followed by the residual effect of butachlor at 1.25 kg/ha *fb* hand weeding at 40 DAT in rice + HW twice at 20 and 40 DAS in okra and blacgram. In 2017 and 2018, oxadiargyl-loaded biochar significantly reduced grass weed density and dry weight. Specifically, grass weed density was reduced by 55.0% in 2017 and 61.3% in 2018, while grass weed dry weight decreased by 50.4% and 65.0%, respectively, compared to the untreated weedy control. These results were consistent with the residual effects observed for other herbicides tested. Sethi *et al.* (2019) reported that grasses' significantly lower weed dry matter was recorded in rice-wheat, while the highest dry matter was recorded in the rice-vegetable pea-maize cropping system.

Sedges weed density and dry weight

During 2017, the residue of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice + HW twice at 20 and 40 DAS in okra and blackgram recorded lower density and dry weight of sedges (16.67 weeds/m^2 and 6.06g/m^2, respectively). This was followed by the residual effect of oxadiargyl-loaded biochar (28.67 weeds/m^2), comparable with oxadiargyl-encapsulated starch and oxadiargyl-loaded zeolite. Whereas, in 2018, the residual effect of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice + HW at 20 and 40 DAS, and that of oxadiargyl loaded biochar and oxadiargyl encapsulated starch were comparable with one another with low density and dry weight for sedges. Density and dry weight of sedges in weedy check varied from 23.6 to 58.6, 28.7 to 70.0 and 49.7 to 63.4, 49.1 to 71.9 compared to herbicidal treatments' residual effect. Weedy check registered significantly higher density and dry weight of sedge than other residual weed control treatments.

Density and dry weight of broad-leaf weeds

The density of broad-leaf weeds was higher in 2018 than in 2017 due to climatic conditions, more conducive to weed growth. Irrespective of the residual effect of herbicide, oxadiargyl-loaded biochar and oxadiargyl encapsulated starch recorded 76.7, 79.3 and 75.3, 77.5% reduced density of BLW during 2017 and 2018, respectively, as compared to the weedy check. Whereas, for BLW, hand weeding twice at 20 and 40 DAS recorded significantly lower BLW dry weight (2.42 and 8.40 g/m^2 in 2017 and 2018, respectively). However, this was comparable with oxadiargyl-loaded biochar in 2017. Nevertheless, in 2018, these two treatments differed significantly from each other. Weedy checks recorded significantly higher BLW density and dry weight of 84.2, 75.8, and 88.3, 66.0% during 2017 and 2018, respectively, than hand weeding twice at 20 and 40 DAS. Mishra *et al.* (2019) reported that maximum density and dry weight of broad -leaf weeds were recorded in rice-maize rotation, followed by rice-wheat and rice-lentil systems.

Weed control efficiency

The residual effect of herbicides applied to previous crops and their weed control treatments showed a marked difference in weed control efficiency in both years (**Table 1**). Weed control efficiency of various weed control treatments on the control of weeds compared to total weed dry weight under weedy check was worked at 40 DAS. The residual effect of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice + HW twice at 20 and 40 DAS recorded maximum weed control efficiency of 83.3 and 79.4% in 2017 and 2018, respectively. Among the residual effects of the preceding herbicide, oxadiargyl-loaded biochar recorded higher weed control efficiency of 65.9% and 70.2% in 2017 and 2018, respectively. Subsequent best treatment was oxadiargyl-encapsulated starch. This might be due to encapsulated/loaded herbicide residue causing significantly higher reduction in the total weed dry weight. Mousa and Eata (2016) reported that the residual effect of herbicides applied in the previous crop is inferior in its effect on weeds associated with succeeding vegetable crops. Bhimwal *et al.* (2019) revealed that higher weed control efficiency could be attributed to lower weed density and dry weight, which leads to higher grain yield. This is in conformity with the earlier findings of Gupta *et al.* (2012) in chickpeas, Panda *et al.* (2015), and Patel *et al.* (2016) in soybean.

Effect on crop growth

The residual effect of encapsulated/loaded herbicide did not significantly influence blackgram seed germination. Even though the two-year mean germination percentage varied from 83.2 to 97.0%, it clearly showed no significant influence of preceding crop encapsulated/loaded herbicide residue on succeeding blackgram. Chavan *et al.* (2018) reported that post-emergence application of quizalofop-ethyl 40g/ha and pre-emergence application of pendimethalin 1.0 kg/ha used in pigeon peas also did not show any residual effect on germination of succeeding blackgram. The weed-free check showed superiority in plant growth and yield attributes, as well as the yield of blackgram, during both experiments. Maximum plant height of 72.1 and 26.3% was observed in the residual effect of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice + HW twice at 20 and 40 DAS during 2017 and 2018, respectively, as compared to the weedy check. The next-order best treatment was the residual effect of oxadiargyl-loaded biochar, comparable with $T_3 > T_2 > T_4$.

Agronomic manipulation alters crop physiology to a certain extent to derive higher economic products. Physiological attributes like LAI, CGR, and

Table 1. Residual effect of encapsulated/loaded herbicide on weed density, weed dry weight and weed control efficiency of blackgram under rice-okra-blackgram cropping system in tropical conditions

Treatment	Weed density at 40 DAS						Weed dry weight at 40 DAS						WCE at 40 DAS	
	Summer, 2017			Summer, 2018			Summer, 2017			Summer, 2018				
	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW	Grasses	Sedges	BLW	2017	2018
Oxadiargyl loaded biochar	6.90 (46.00)	5.53 (28.67)	3.65 (11.33)	6.22 (36.67)	5.15 (24.67)	4.16 (15.33)	4.87 (21.74)	3.76 (12.11)	2.37b (3.61)	3.52 (10.36)	3.55 (10.64)	2.90 (6.42)	65.9	70.2
Oxadiargyl loaded zeolite	7.19 (49.67)	6.02 (34.33)	3.83 (12.67)	6.63 (42.00)	6.51 (40.33)	4.80 (21.00)	5.20 (25.04)	4.21 (15.72)	2.65 (5.04)	3.71 (11.75)	4.03 (14.25)	3.36 (9.29)	58.3	61.7
Oxadiargyl encapsulated starch	7.04 (47.67)	5.86 (32.33)	3.74 (12.00)	6.27 (37.33)	5.43 (27.67)	4.32 (16.67)	4.89 (22.12)	3.74 (12.06)	2.55 (4.50)	3.59 (10.88)	3.56 (10.73)	3.65 (11.43)	64.7	64.1
Oxadiargyl encapsulated water-soluble polymer	7.46 (53.67)	6.95 (46.67)	4.52 (18.67)	7.05 (47.67)	7.22 (50.33)	5.03 (23.33)	5.20 (25.14)	4.23 (15.93)	2.95 (6.76)	3.90 (13.23)	4.44 (17.80)	3.56 (10.69)	56.4	54.7
Oxadiargyl 100 g/ha	7.50 (54.33)	7.42 (53.00)	5.53 (28.67)	7.37 (52.33)	7.79 (58.67)	5.97 (33.67)	5.45 (27.73)	4.31 (16.58)	3.37 (9.38)	4.21 (15.73)	4.77 (20.79)	3.90 (13.25)	51.1	46.0
Butachlor 1.25 kg/ha *fb* HW at 40 DAT	4.72 (20.33)	4.32 (16.67)	3.11 (7.67)	4.08 (14.67)	4.89 (22.00)	3.83 (12.67)	3.43 (9.79)	2.84 (6.06)	2.10 (2.42)	2.24 (3.03)	3.09 (7.55)	3.22 (8.40)	83.3	79.4
Weed free check	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	1.41 (0.00)	100.0	100.0
Weedy check	10.20 (102.3)	8.44 (69.33)	7.09 (48.67)	8.67 (74.00)	9.18 (82.33)	7.35 (52.33)	7.62 (56.11)	5.90 (32.93)	4.73 (20.71)	5.57 (29.57)	6.31 (37.87)	5.15 (24.68)	-	-
LSD (p=0.05)	0.68	0.62	0.68	0.70	0.54	0.42	0.44	0.35	0.51	0.52	0.30	0.38		
CV (%)	5.94	6.16	9.44	6.67	5.20	5.24	5.33	5.26	10.55	8.41	8.54	6.44		

Figures in parentheses indicate original values subjected to square root $\sqrt{x+2}$ transformation

RGR differed in both years of experiments. At 50 DAS, the residual effect of butachlor at 1.25 kg/ ha *fb* HW at 40 DAT in rice + HW twice at 20 and 40 DAT significantly increased the LAI (4.87 and 4.52 during 2017 and 2018, respectively) over other weed management practices. Among the residual effects of herbicide in preceding crop, oxadiargyl-loaded biochar registered slightly higher leaf area index of 46.4 and 49.7% compared to weedy check during 2017 and 2018, respectively, comparable with other residual effect of herbicide. The favourable weed-free situation and higher nutrient uptake might have resulted in taller plants with a higher leaf area index (Bommayasamy *et al.*, 2018). Crop growth rate altered with the age of the crop due to gradual changes in photosynthetic efficiency. The CGR determined crop production as a function of light interception in the crop canopy. At 50 DAS to harvest stage, the CGR ranged between 2.21 to 4.51 and 1.74 to 3.39 g/m^2/day during 2017 and 2018, respectively. The residual effect of butachlor at 1.25 kg/ha *fb* HW at 40 DAT in rice+ HW twice at 20 and 40 DAS recorded higher crop growth rates of 2.69 and 2.53 g/m^2/day during the first and second year of the experiment, respectively, which was comparable with oxadiargyl loaded biochar in 2017. In 2018, all other treatments were comparable except for the residual effect of oxadiargyl 100 g/ha and weedy check. Among the residual effects of herbicide, higher RGR was recorded under the residual effect of oxadiargyl encapsulated water-soluble polymer at 50 DAS to harvest stage during 2017, which was comparable with oxadiargyl at 100 g/ha and oxadiargyl loaded zeolite. Whereas, in 2018, the residual effect of the preceding rice herbicide did not show any significant difference among the weed control treatments. Mundra and Maliwal (2012), Bommayasamy and Chinnamuthu (2019), Ahlawat *et al.* (2024) reported that improved growth attributes are due to reduced weed competition with crops, which creates favourable environmental conditions for crop growth and development.

Effect on yield attributes and yield

Yield attributes of blackgram, *viz.* clusters/ plant, seeds/plant and grain yield were significantly influenced by the encapsulated/loaded herbicide residue of the preceding rice crop, while test weight did not show many variations on the yield attributes of blackgram (**Table 3**). The highest clusters/plant and seeds/plant were observed under weed-free check. Among the residual effects of herbicide, oxadiargyl-loaded biochar recorded significantly higher clusters/plant (4.8, 7.2%) with higher seeds/ plant (20.0, 26.2%) compared to oxadiargyl-loaded zeolite during 2017 and 2018, respectively. However, these treatments were on par with each other. The weedy check recorded the lowest number of clusters/plants of 5.50 and 5.43 and 61.2 and 81.1 seeds/plants in 2017 and 2018, respectively. The difference in seed test weight was not significant due to the residual effect of herbicide in both years. As assessed through the weed index, the extent of yield reduction due to weed competition has indicated the suppressing effect of oxadiargyl-loaded biochar on weeds. It had minimum weed competition and maximum seed yield of 108 and 101 kg of higher blackgram seed yield during 2017 and 2018, respectively, compared to the weedy check. It might be due to better growth and yield attributes that led to efficient utilization of resources, which in turn improved the yield attributes and yield. Volova *et al.* (2020) and Bommayasamy and Chinnamuthu (2021) found that encapsulated/loaded oxadiargyl herbicide

Table 2. Residual effect of encapsulated/loaded herbicide on crop growth attributes of blackgram under rice-okra-blackgram cropping system in tropical conditions

Treatment	Summer, 2017					Summer, 2018				
	Germination (%)	Plant height (cm)	LAI at 50 DAS	50 DAS - Harvest CGR (g/m^2/d)	50 DAS - Harvest RGR (g/g/d)	Germination (%)	Plant height (cm)	LAI at 50 DAS	50 DAS - Harvest CGR (g/m^2/d)	50 DAS - Harvest RGR (g/g/d)
Oxadiargyl loaded biochar	90.3	32.3	4.32	2.34	0.0115	90.0	34.6	4.31	2.09	0.0160
Oxadiargyl loaded zeolite	88.7	30.1	3.89	2.33	0.0132	90.2	33.7	3.95	1.85	0.0185
Oxadiargyl encapsulated starch	81.3	30.4	4.10	1.89	0.0115	84.4	34.3	4.07	1.93	0.0154
Oxadiargyl encapsulated water-soluble polymer	89.7	29.6	3.82	2.09	0.0142	93.0	33.1	3.53	1.81	0.0189
Oxadiargyl 100 g/ha	84.0	27.6	3.21	2.12	0.0135	87.9	32.6	3.38	1.80	0.0202
Butachlor 1.25 kg/ha *fb* HW at 40 DAT	90.3	38.2	4.87	2.69	0.0121	96.4	36.6	4.52	2.53	0.0181
Weed free check	95.7	40.7	4.94	4.51	0.0129	98.2	41.2	4.58	3.39	0.0211
Weedy check	82.7	22.2	2.95	2.11	0.0111	82.0	29.6	2.88	1.74	0.0200
LSD (p=0.05)	NS	5.5	0.56	0.59	0.0036	NS	3.8	0.61	0.77	NS

Table 3. Residual effect of encapsulated/loaded herbicide on yield attributes and yield of blackgram under rice-okra-blackgram cropping system in tropical conditions

Treatment	Summer, 2017				Summer, 2018			
	Clusters / plant	Seeds/ plant	Test weight (g)	Seed yield (kg/ha)	Clusters/ plant	Seeds / plant	Test weight (g)	Seed yield (kg/ha)
Oxadiargyl loaded biochar	6.60	110.6	6.13	444	6.57	132.9	6.07	416
Oxadiargyl loaded zeolite	6.30	92.2	5.80	370	6.13	105.3	5.97	347
Oxadiargyl encapsulated starch	6.40	105.4	5.90	426	6.63	125.4	6.03	399
Oxadiargyl encapsulated water-soluble polymer	5.90	91.2	5.80	366	5.83	104.2	5.83	343
Oxadiargyl 100g/ha	5.50	68.5	5.60	358	5.80	83.2	5.80	336
Butachlor 1.25 kg/ha *fb* HW at 40 DAT	8.40	184.1	6.20	655	8.17	154.1	6.17	614
Weed free check	10.20	251.0	6.60	842	8.80	196.7	6.30	790
Weedy check	5.10	61.2	5.26	336	5.37	81.1	5.60	315
LSD (p=0.05)	0.77	17.1	NS	50	0.61	19.5	NS	79

with biochar and zeolite released active ingredient for a longer time, which reduced the growth of later emerging weed and build-up of soil weed seed bank. Yadav *et al.* (2019), Gupta *et al.* (2019) reported that lesser infestation of weeds increases translocation of photosynthesis from source to sink. In this situation, it may enhance the seed production ratio of chickpeas. The lowest yield attributes, *viz.* clusters/ plant, seeds/plant and seed yield, were recorded under weedy check. It might be due to increased weed competition with unchecked weed growth. The productivity of crops mainly depends on efficient and effective resource management, particularly weeds. Parthipan *et al.* (2013), Rana *et al.* (2019) and Anand and Singh (2023) also have reported similar findings.

Conclusion

Conventional agrochemical formulations may be replaced by encapsulation/loaded herbicide formulations to help avoid treatment with excess amounts of active substances and offer ecological and economic advantages. The results clearly indicated the residual effect of oxadiargyl-loaded biochar and zeolite, which can release active ingredients for a longer time, with reduced growth of later emerging weeds and build-up of soil weed seed bank.

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