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RESEARCH ARTICLE

Chemical weed management in transplanted rice and its residual effect on follow up lathyrus (*Lathyrus sativus* L.)

Kalyan Jana*[1], Saikat Biswas[2], Arup Sarkar[1], Ramyajit Mondal[3] and Krishnendu Mondal[4]

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ABSTRACT

A field experiment was conducted at Central Research Farm, Gayeshpur, Nadia, West Bengal, India during the *Kharif* (rainy) seasons of 2019-20 and 2020-21 to evaluate bio-efficacy and phytotoxicity of herbicide pretilachlor 50% EC in transplanted rice and its residual effect on *utera*/*paira* (follow up) crop lathyrus. The experiment was placed in randomized complete block design comprising 10 treatments (pretilachlor 50% EC 375, 500, 625, 750, 875 g/ha, pendimethalin 30% EC 1000, 1500 g/ha, Butachlor 50% EC 1250 g/ha, hand weeding at 15 and 30 days after transplanting and unweeded control) and replicated thrice. Pooled results revealed that application of pretilachlor 50% EC 625 g/ha was superior over pendimethalin and butachlor remained equally effective as hand weeding in ensuring high weed control efficiency. Consequently, 4.38 and 4.98 t/ha of grains and straw yields, respectively were obtained at pretilachlor 50% EC 625 g/ha. Further, no phytotoxic effect on crop as well as on soil health was observed under application of that herbicide. Performance of *paira* crop lathyrus did not get hampered due to herbicidal applications in rice due to dissipation of toxicity from soil. Therefore, early post-emergence application of pretilachlor 50% EC 625 g/ha can be safely recommended for transplanted *Kharif* rice cultivation in Gangetic plains of West Bengal.

Keywords: Chemical weed management, Follow up lathyrus crop, *Lathyrus sativus,* Rice, Weed control efficiency, Yield

INTRODUCTION

Rice (*Oryza sativa* L.) plays a vital role in food and livelihood security for almost every household. It is a principal source of food for more than half of the world's population and also an important cereal crop next to wheat which accounts for the major dietary energy requirement of Asian rural people as more than 90 % of rice is grown and consumed in Asia.

About 56% of gross cropped area of Bengal has been occupied by rice and ranks first in cultivated area providing livelihood for about 120-150 million rural households. It contributes about 43% of whole food grain production and 46 % of total cereal production in India (Anonymous 2021). Out of 782 million tonnes of global rice production from 167.1 million hectares, India produced 116.4 mt in 44.5 mha (rainy season: 102.1 mt from 39.27 mha) (FAO, 2020; GOI, 2020). Weeds are most severe and widespread biological constraints to crop production in India and weeds alone cause 33% of losses out of total losses due to pests (Verma *et al.* 2015). Weeds are considered as a major contributors of rice yield loss generally ranged between 18-20% in transplanted rice, 30-35% in direct sown puddled rice and more than 50% in direct seeded upland rice. Weed problem is now a major concern of rice growers throughout the world which claimed to reduce 45-55% yield of rice (Bouman *et al*. 2005). Therefore, proper management of weeds is the fundamental requisite for ensuring quality rice production. In general, weeds problem in transplanted paddy is lower than that of direct-seeded rice (Rao *et al.* 2007). But, in situations where continuous standing water cannot be maintained particularly during the first 45 days, weed infestation in transplanted rice may be as high as direct-seeded rice. Weeds can reduce the grain yield of dry direct-seeded rice (DSR) by 75.8%, wet-seeded rice (WSR) by 70.6% and transplanted rice (TPR) by 62.6% (Singh *et al.,* 2004). The pre-emergence herbicide protects the crop with early and effective control of weeds that assists in maximizing yields, regardless of the production potential that can minimize the application of post-emergence herbicide

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and protect against early-season weed competition. Among the winter growing annual pulse crops, *Lathyrus sativus* (Lathyrus or Khesari) is considered as an 'insurance crop' due to its remarkable drought tolerating ability with minimal external inputs which can easily be grown as a relay crop under rice fallow situation (Bhowmick *et al.*, 2014). Basically, lathyrus is a protein-rich pulse crop (28%) containing considerable proportions of essential minerals like calcium, phosphorus and iron with reliable yields and therefore, believed to be an ideal legume for resource-poor farmers. Considering all these facts, the present experiment was planned to evaluate the weed management through application of chemical herbicide in transplanted *Kharif* rice and its residual effect on performance of *paira* (follow up) crop lathyrus in lower Gangetic plains of West Bengal, India.

MATERIALS AND METHODS

The field experiment was carried out at Central Research Farm, Gayeshpur, Nadia, West Bengal, India during 2019-20 and 2020-21 under randomized complete block design (RCBD) comprising 10 treatments: pretilachlor 50% EC 375 g/ha, pretilachlor 50% EC 500 g/ha, pretilachlor 50% EC 625 g/ha, pretilachlor 50% EC 750 g/ha, pretilachlor 50% EC 875 g/ha, pendimethalin 30% EC 1000 g/ha, butachlor 50% EC 1250 g/ha, hand weeding at 15 and 30 days after transplanting (DAT), unweeded control, pendimethalin 30% EC 1500 g/ha), replicated thrice. Rice variety *'IET-4786'* was sown in nursery and then transplanted on the main field at a spacing of 20 × 15 cm with 2 seedlings /hill. Gap filling was done at 7 DAT. Individual plot size was 4 × 3 m. To test herbicides pretilachlor 50% EC and two standard check herbicides, pendimethalin 30% EC and butachlor 50% EC at various doses were applied with the spray volume of 500 L/ha through knapsack sprayer under standing water of rice field at early post-emergence stage (4 DAT). Recommended doses of fertilizers (60:30:30 N:P:K kg/ha) was applied through urea, S.S.P. and M.O.P. ($1/4^{th}$ N, full P and $3/4^{th}$ K as basal during final land preparation and ½ N at active tillering stage *i.e*. 21 DAT and 1/4th N and K at panicle initiation stage *i.e*. 42 DAT). 2-3 cm standing water from 2-30 DAT and 4-5 cm standing water for next 7-10 days were maintained, after which soil was allowed to saturate under no application of water for 4-5 days. After heading to hard dough stage intermittent irrigation (2 cm water application at 2 days interval) was done up to 30 days after heading. Water supply was stopped at 12-15 days before harvesting. Before harvesting of *Kharif* rice, *paira* (follow up) crop lathyrus (cv. *Nirmal*) was sown on the experimental field to evaluate residual toxic effect of applied herbicide on succeeding crop lathyrus.

Observations included weed density, weed dry weight and weed control efficiency (WCE) of dominant weed flora in rice field at 30, 45 and 60 days after application of herbicide as well as yield and yield attributes *i.e*. grain yield, straw yield, biological yield and harvest index of transplanted *Kharif* rice. Production economics of rice was also estimated. Furthermore, germination percentage, plant height, pods/plant, seeds/pod and seed yield of *paira* crop lathyrus at harvest were noted. Soil samples of 0-15 cm depth were collected from experimental plots at different interval and toxicity on soil rhizospheric micro-organisms (bacteria, fungi and actinomycetes) was analyzed by counting on agar plates as number of viable cells per gram of soil using Thronton's agar medium, Martin-Rose Bengal Streptomycin agar medium and Jensen's agar medium respectively through serial dilution technique, pour plate method (Pramer and Schmidt, 1965) followed by incubation at 28±1°C. The counts were taken at 5^{th} day of incubation. Phytoxicity study involved visual symptoms (epinasty, hyponasty, vein clearing, wilting and leaf injury) noted at 1, 3, 5, 7, 15, 30 DAA and represented as per phytotoxicity rating scale (0, 1-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90 and 91-100% crop injury were represented by 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 scales, respectively).

Data recorded from the field as well as the laboratory were statistically analyzed through analysis of variance (ANOVA) method as prescribed by Panse and Sukhatme (1985) in online OP-stat portal (Sheoran *et al.*, 1998) and treatment means were compared through least significant difference (LSD) at 5% level of significance. As wide variation existed in the original data sets of weed densities and dry weights, they were subjected to square root transformation ($\sqrt{x+0.5}$) for improving the homogeneity.

RESULTS AND DISCUSSION

Dominant weed flora

Observations during both the years of experiment expressed that rice field was mostly dominated by grasses like *Echinochloa crus-galli*, *Echinochloa colona*, sedges like *Cyperus difformis*, *Fimbristylis miliacea* and broad leaf weeds like *Ludwigia parviflora*, *Monochoria vaginalis*, *Alternanthera philoxeroides*, *Marsilea quadrifolia*. Other noticeable weed floras were *Leersia hexandra*, *Ammania baccifera*, *Echinochloa formosensis*, *Cyperus rotundus*, *Cyperus iria*, *Commelina benghalensis*, *Oxalis corniculate etc*. Shahabuddin *et al.* (2016) and Mondal *et al.* (2019) also noticed similar types of weed flora in transplanted rice field.

Weed density

Weed density (no./m^2) at 30, 45 and 60 days after application (DAA) of herbicides represent the efficacy of various weed management practices on suppression of weeds. Pooled value stated that hand weeding at 15 and 30 DAT significantly reduced weed density of rice field over unweeded control, which was followed by various herbicidal applications. Among chemical treatments, pretilachlor 50% EC 625 g/ha recorded lowest population in all three categories of weed biomass during 30, 45 and 60 DAA (**Table 1**). It was also noted that pretilachlor 50% EC at various doses were superior over butachlor 50% EC and pendimethalin 30% EC in suppression of dominant weed floras of rice field. Application of selective herbicide, pretilachlor effectively reduced weed density from rice field, which might be due to its inhibitory effect on cell division of weeds (Challam and Thabah, 2018). Moreover, blocking of protein, nucleic acid and gibberelic acid synthesis by pretilachlor might be another reason for suppression of weeds in rice field (Das 2008).

Weed dry weight

Weed dry weight (g/m^2) is most appropriate measure of various weed management practices. Pooled results depicted maximum dry weights of all the categories of weeds under unweeded control as no measure was incorporated there to suppress weeds. Among various weed management practices, hand weeding at 15 and 30 DAT mostly reduced dry weights of grass, sedges and broad leaf weeds indicating its efficacy of suppressing weeds of rice field, whereas among herbicidal application, pretilachlor 50% EC 625 g/ha also significantly reduced weed dry weights at 30, 45 and 60 DAA and these values were statistically at par (**Table 2**). The result was in agreement with the finding of Mondal *et al.* (2019) who similarly noticed that pretilachlor 50% EC reduced weed biomass better than other herbicidal applications like butachlor in transplanted rice.

Table 1. Weed density (no./m^2) of transplanted *Kharif* rice as influenced by different weed control measures (pooled value of two years)

Treatment	Weed density (no./m^2)								
	30 DAA			45 DAA			60 DAA		
	Grass	Sedges	Broad-leaf	Grass	Sedges	Broad-leaf	Grass	Sedges	Broad-leaf
Pretilachlor 375 g/ha	1.46(1.4)	1.98(1.57)	2.51 (1.73)	3.02(1.88)	3.76(2.06)	4.08(2.14)	3.68(2.04)	3.94(2.10)	4.32(2.19)
Pretilachlor 500 g/ha	1.43(1.39)	1.92(1.56)	2.42(1.71)	2.74(1.8)	2.49(1.73)	3.84(2.08)	3.46(1.98)	3.71(2.05)	4.05(2.13)
Pretilachlor 625 g/ha	1.34(1.36)	1.81(1.52)	2.11(1.62)	2.21(1.65)	2.14(1.62)	3.35(1.96)	3.12 (1.9)	3.18(1.91)	3.13(1.90)
Pretilachlor 750 g/ha	1.42(1.39)	1.82(1.52)	2.34(1.69)	2.31(1.68)	2.32(1.68)	3.41(1.98)	3.34(1.95)	3.25(1.93)	3.39(1.97)
Pretilachlor 875 g/ha	1.40(1.38)	1.84(1.53)	2.20(1.64)	2.26(1.66)	2.28(1.67)	3.54(2.01)	3.24(1.93)	3.45(1.98)	3.32(1.94)
Pendimethalin 1000 g/ha	1.52(1.42)	2.24(1.66)	2.76(1.81)	3.83(2.08)	4.41(2.22)	4.51(2.24)	3.87(2.09)	4.29(2.18)	4.87(2.31)
Butachlor 1250 g/ha	1.67(1.47)	2.43(1.71)	2.87(1.84)	3.88(2.09)	4.62(2.26)	4.83(2.31)	3.98(2.11)	4.56(2.24)	5.36(2.42)
Hand weeding at 15&30 DAT	1.28(1.33)	1.78(1.51)	1.98(1.57)	2.18(1.64)	2.11(1.62)	3.28(1.94)	3.04(1.88)	3.08(1.89)	3.08(1.89)
Unweeded Control	2.57(1.75)	4.13(2.15)	3.54(2.01)	4.62(2.26)	5.78(2.51)	5.41(2.43)	4.74(2.28)	4.96(2.33)	6.17(2.58)
Pendimethalin 1500 g/ha	1.49(1.41)	2.02(1.59)	2.63(1.77)	3.72(2.05)	4.36(2.2)	4.35(2.2)	3.64(2.03)	4.17(2.16)	5.09(2.36)
LSD (p=0.05)	0.24	0.64	0.38	0.31	0.54	0.37	0.26	0.22	0.24

*Data presented in the table indicated square root transformed value ($\sqrt{x+0.5}$) of original data set

Table 2. Weed dry weight (g/m^2) of transplanted *Kharif* rice as influenced by different weed control measures (pooled value of two years)

Treatment	Weed dry weight(g/m^2)								
	30 DAA			45 DAA			60 DAA		
	Grass	Sedges	Broad leaf	Grass	Sedges	Broad-leaf	Grass	Sedges	Broad-leaf
Pretilachlor 375 g/ha	15.84(4.0)	17.82(4.3)	20.17(4.5)	16.29(4.1)	18.23(4.3)	21.24(4.7)	16.31(4.1)	18.54(4.4)	23.78(4.9)
Pretilachlor 500 g/ha	14.58(3.8)	17.12(4.2)	19.12(4.4)	15.58(4.0)	17.42(4.2)	20.42(4.6)	16.05(4.1)	17.62(4.2)	22.13(4.7)
Pretilachlor 625 g/ha	11.36(3.4)	15.12(3.9)	16.14(4.1)	12.18(3.6)	13.16 (3.7)	17.35(4.2)	12.52(3.6)	14.23(3.8)	18.52(4.4)
Pretilachlor 750 g/ha	13.89(3.7)	17.05(4.2)	16.24(4.1)	13.68(3.8)	17.23(4.2)	18.25(4.3)	14.26(3.8)	15.41(4.0)	19.47(4.5)
Pretilachlor 875 g/ha	14.24(3.8)	16.89(4.2)	18.43(4.3)	14.82(3.9)	17.27(4.2)	19.57(4.5)	16.21(4.1)	16.52(4.1)	21.21(4.6)
Pendimethalin 1000 g/ha	18.37(4.3)	17.92(4.3)	21.45(4.7)	17.08(4.2)	21.37(4.7)	23.54(4.9)	16.51(4.1)	20.12(4.5)	24.73(5.0)
Butachlor 1250 g/ha	17.69(4.2)	18.24(4.3)	20.42(4.6)	16.81(4.2)	22.42(4.8)	22.87(4.8)	17.42(4.2)	19.13(4.4)	23.58(4.9)
Hand weeding at 15&30 DAT	11.04(3.3)	14.67(3.9)	14.56(3.9)	11.95(3.5)	13.05(3.7)	17.08(4.2)	12.12(3.5)	13.37(3.7)	17.85(4.3)
Unweeded Control	19.89(4.4)	23.74(4.9)	25.28(5.1)	20.39(4.6)	28.21(5.4)	28.67(4.5)	20.24(4.5)	25.48(5.1)	28.23(5.4)
Pendimethalin 1500 g/ha	17.62(4.5)	16.45(4.1)	20.34 (4.6)	15.45(4.0)	20.82(4.6)	22.25 (4.7)	16.32(4.1)	19.23(4.4)	23.56(4.9)
LSD (p=0.05)	1.22	0.81	2.54	0.72	1.12	0.53	0.72	0.48	0.62

*Data presented in the table indicated square root transformed value ($\sqrt{x+0.5}$) of original data set

Weed control efficiency

Weed control efficiency also similarly varied according to various weed management practices. Pooled results (**Table 3**) showed that hand weeding at 15 and 30 DAT ensured best value of weed control efficiency at 30, 45 and 60 DAA. However, among the various herbicidal measures, pretilachlor 50% EC 625 g/ha was almost equally effective as that of hand weeding during the 30, 45 and 60 DAA period of observations. pretilachlor 50% EC 625 g/ha ensured the best results of weed control efficiency at 30, 45 and 60 DAA which was followed by same herbicide 750 g/ha, 875 g/ha, 500 g/ha and 375 g/ha (**Table 3**). Further, impairment of growth and cell division by the herbicidal mode of action led to death of weed flora of rice field. These facts might be there behind the high WCE in rice field by the test herbicide pretilachlor 50% EC as observed in the present experiment.

Yield and yield attributes

Pooled results revealed that yield of transplanted *Kharif* rice varied significantly in response to various weed management practices. Pooled results showed that hand weeding at 15 and 30 DAT recorded maximum numbers of productive tillers/m^2 and number of filled grains/panicle, whereas among chemical treatments, pretilachlor 50% EC 625 g/ha reported the best value which was better than other doses of Pretilachlor, Butachlor and pendimethalin applications. The maximum grain and straw yields of transplanted *Kharif* rice were achieved when hand weeding was done at 15 and 30 DAT. However, among chemical measures, maximum grain and straw yields were attained under application of pretilachlor 50% EC 625 g/ha which remained almost equally effective as hand weeding at 15 and 30 DAT. Consequently, biological yield of transplanted *Kharif* rice also followed the similar trend. Harvest index of transplanted *Kharif* rice was dependent on economic (grain) and biological yields. Pooled results on harvest index (**Table 4**) however explored slightly different trends of grain, straw and biological yields of transplanted *Kharif* rice. Highest harvest index of transplanted *Kharif* rice was observed when pretilachlor 50% EC 750 g/ha was applied which was closely followed by application of pretilachlor 50% EC 625 g/ha and hand weeding at 15 and 30 DAT. The lowest grain, straw, biological yields and harvest index of transplanted *Kharif* rice were obtained from unweeded control (**Table 4**).

Effect on *paira* crop lathyrus

Experimental results (**Table 5**) explored that there was no residual effect of herbicidal application

Table 3. Weed control efficiency (%) of transplanted *Kharif* rice as influenced by different weed control measures (pooled value of two years)

Treatment	Weed control efficiency (%)								
	30 DAA			45 DAA			60 DAA		
	Grass	Sedges	Broad-leaf	Grass	Sedges	Broad-leaf	Grass	Sedges	Broad-leaf
Pretilachlor 375 g/ha	72.69	75.14	73.65	73.59	72.43	75.32	7311	72.48	75.26
Pretilachlor 500 g/ha	71.61	77.60	81.89	65.70	71.03	78.83	64.38	70.08	77.56
Pretilachlor 625 g/ha	78.98	76.82	76.94	78.28	76.59	80.21	76.23	76.22	81.21
Pretilachlor 750 g/ha	75.04	73.33	74.42	74.27	73.30	72.34	73.26	72.98	73.19
Pretilachlor 875 g/ha	76.12	77.64	76.03	75.41	79.27	78.59	72.23	80.18	79.23
Pendimethalin 1000 g/ha	67.92	66.44	71.51	71.82	63.73	65.04	71.01	63.29	64.27
Butachlor 1250 g/ha	84.59	83.87	87.92	75.37	77.19	78.12	74.49	76.62	78.17
Hand weeding at 15&30 DAT	89.23	88.23	92.54	88.72	91.22	91.39	88.65	90.89	91.89
Unweeded control	76.54	76.17	78.38	72.32	74.15	73.25	73.21	73.63	72.19
Pendimethalin 1500 g/ha	79.85	78.62	78.83	76.62	75.19	74.19	76.32	74.23	73.96
LSD (p=0.05)	--	--	--	--	--	--	--	---	---

Table 4. Effect of different weed control measures on yield and yield attributes of transplanted *Kharif* rice (pooled of two years)

Treatment	No. of productive tillers/m^2	No. of filled grains/ panicle	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Pretilachlor 375 g/ha	316	80.11	3.89	4.71	45.06
Pretilachlor 500 g/ha	328	82.64	4.02	4.78	45.71
Pretilachlor 625 g/ha	336	83.12	4.39	4.98	46.52
Pretilachlor 750 g/ha	320	81.58	3.97	4.52	47.00
Pretilachlor 875 g/ha	312	76.82	3.82	4.72	44.57
Pendimethalin 1000 g/ha	284	72.76	3.54	4.46	44.14
Butachlor 1250 g/ha	299	74.10	3.68	4.30	46.09
Hand weeding at 15&30 DAT	345	84.18	4.46	5.08	46.60
Unweeded control	237	65.21	2.12	4.84	30.35
Pendimethalin 1500 g/ha	290	73.46	3.59	4.77	42.48
LSD (p=0.05)	1.88	0.74	0.02	0.03	0.21

in transplanted *Kharif* rice on *paira* (follow up) crop lathyrus. Germination % at 10 DAS, plant height, pods/plant, seeds/pod and seed yield of lathyrus did not significantly vary under herbicidal application in previous crop rice. However, among various herbicides applied in transplanted *Kharif* rice, performance of *paira* crop lathyrus was better observed under pretilachlor 50% EC at various doses. The plant height, pods/plant, seeds/pod, seed yield of lathyrus and germination % at 10 DAS were noticed best where previously herbicide, pretilachlor 50% EC 625 g/ha was applied in transplanted *Kharif* rice as weed control measures (**Table 5**). Hand weeding in transplanted *Kharif* rice at 15 and 30 DAT closely followed the results obtained from application of herbicide, pretilachlor 50% EC 625 g/ha in transplanted *Kharif* rice since hand weeding in rice can preserve the soil nutrient and moisture for next crop (lathyrus) as it was devoid of any toxic effect. No residual toxic effects of herbicides on *paira* crop lathyrus might be due to the degradation of herbicidal molecules by the microorganisms for their own nourishment (Bera and Ghosh 2013).

Soil microbial population

Pooled results (**Table 6**) showed that initially there were no statistically significant variations of bacterial, fungal and actinomycetes populations in the rhizosphere regions of rice in experimental plots. However, after application of herbicides, the microbial populations in the experimental soil varied significantly. There were drastic reductions of bacterial, fungal and actinomycetes populations in soil soon after application of herbicides. Bera and Ghosh (2013) also reported sudden declines of microbial populations soon after application of herbicides in rice field as concentrations of toxic chemicals were high on soil at the time of application which affected physiological process of the microbial community. However, among different herbicides, reduction of microbial populations was comparatively less in pretilachlor 50% EC. At 30 DAA, slight recoveries of microbial populations from 10 days after application were found, which continued up to 60 DAA. It might be due to gradual fading of herbicidal efficacy as days progressed. However, from 30 DAA onwards, increments in microbial populations were noticed as bacteria, fungi and actinomycetes population continued their recovery considerably and at 60 DAA, bacterial, fungal and actinomycetes population exceed the initial microbial populations. The result might be due to the fact that soil micro-organisms undergone effective degradation of herbicidal molecule to obtain carbon-based products for their own nourishment and multiplication (Biswas and Dutta 2019).

Table 5. Germination (%), seed yield and ancillary characters of *paira* crop lathyrus as influenced by different weed control measures applied in transplanted *Kharif* rice (pooled of two years)

Treatment	Germination % at 10 DAS	Plant height (cm)	Pods/plant	Seeds/pod	Seed yield (kg/ha)
Pretilachlor 375 g/ha	82	86.5	32	3.2	880
Pretilachlor 500 g/ha	81	88.3	31	3.1	865
Pretilachlor 625 g/ha	85	92.2	33	3.4	898
Pretilachlor 750 g/ha	80	85.2	30	3.1	872
Pretilachlor 875 g/ha	83	85.3	31	3.2	859
Pendimethalin 1000 g/ha	82	82.2	32	2.9	862
Butachlor 1250 g/ha	81	84.5	30	3.1	873
Hand weeding at 15&30 DAT	85	90.1	32	3.3	882
Unweeded control	82	89.2	31	3.2	876
Pendimethalin 1500 g/ha	84	83.5	29	2.8	862
LSD (p=0.05)	NS	NS	NS	NS	NS

Table 6. Microbial population of the experimental soil at various days after herbicide application (pooled of two years)

Treatment	Bacteria (CFU x 10^6 /gm of soil)				Fungi (CFU x 10^4 /gm of soil)				Actinomycetes (CFU x 10^5 /gm soil)			
	Initial	10 DAA	30 DAA	60 DAA	Initial	10 DAA	30 DAA	60 DAA	Initial	10 DAA	30 DAA	60 DAA
Pretilachlor 375 g/ha	35.52	32.74	34.54	85.62	55.31	36.52	45.53	88.45	55.34	37.72	43.41	89.57
Pretilachlor 500 g/ha	35.75	30.42	35.85	88.23	56.85	32.35	42.64	96.68	56.68	33.52	41.55	99.38
Pretilachlor 625 g/ha	34.66	29.56	36.35	96.82	54.68	30.84	44.38	108.47	54.29	33.59	44.52	102.17
Pretilachlor 750 g/ha	35.54	31.82	35.23	99.71	55.82	28.78	42.89	108.42	55.75	32.87	42.68	98.73
Pretilachlor 875 g/ha	36.72	30.24	35.21	102.57	55.93	27.37	43.47	107.23	56.83	32.18	43.75	95.96
Pendimethalin 1000 g/ha	35.57	24.23	32.72	84.56	56.57	22.98	40.12	81.46	53.12	28.18	40.85	91.43
Butachlor 1250 g/ha	35.38	22.82	34.51	80.41	55.41	21.42	38.45	78.67	54.58	27.54	38.12	88.64
Hand weeding at 15&30 DAT	36.32	56.18	59.64	112.52	54.34	58.72	59.56	108.65	56.24	62.57	65.92	101.95
Unweeded control	35.62	55.27	57.14	107.26	55.57	56.23	57.24	82.57	54.32	61.29	64.58	93.57
Pendimethalin 1500 g/ha	36.74	22.58	34.25	76.41	54.28	20.45	37.89	74.58	53.47	25.87	36.87	84.34
LSD (p=0.05)	NS	3.21	4.22	6.21	NS	3.22	5.21	6.23	NS	2.26	3.23	3.51

Phytotoxicity

Phytotoxicity study (**Table 7**) revealed that apart from pendimethalin 30% EC 1500 g/ha, no other herbicide application showed phytotoxicity symptoms such as epinasty, hyponasty, vein clearing, wilting and leaf injury on rice. The observation was in line with the finding of Mondal *et al.* (2019) in transplanted winter rice. Selective nature of the herbicide might be the reason behind the observation. pendimethalin 30% EC at high dose *i.e.* 1500 g/ha showed 1-20% phytotoxic symptoms which were visible mostly from 5 DAA and those slightly increased as days progressed up to 30 DAA on rice. Bandopadhyay and Choudhury (2009) also similarly reported phytotoxic effects of pendimethalin at higher doses on mustard.

Economics

Production economics of transplanted *Kharif* rice showed variations under different weed control measures (**Table 8**). The maximum cost of cultivation (₹ 51709/ha) was incurred when hand weeding was done due to high labour involvement to remove weeds from the field, while unweeded control fetched lowest cost of cultivation (₹ 44209/ha) due to no weed control measure. Based on the market price and quantity required for weed control, cost of cultivation varied among chemical herbicide treated plot. Yet, less cost of cultivation was required for pretilachlor treated plots over other herbicides. Due to better positive impact on yield of rice, hand weeded plot showed maximum gross return (₹ 90780/ha), while unweeded control made lowest gross and net returns (₹ 44970 and ₹ 761/ha) as well as B:C (1.02) due to negative impact of weeds on growth and yield of crop. pretilachlor 50% EC 625 g/ha recorded highest net return (₹ 42994/ha) and B:C (1.93) among all the treatments due to its greater weed control efficiency at less cost, which reflected positively on growth, yield and economics of transplanted *Kharif* rice. Similar observation was noted by Biswas *et al.* (2021) in cotton.

Conclusion

The present investigation confirms the greater efficacy of pretilachlor 50% EC in controlling weeds from transplanted *Kharif* rice field than butachlor and pendimethalin. Further, it has proved its equal effectiveness and emerged as a potential alternative of uneconomical, labour-intensive hand weeding. pretilachlor 50% EC has also confirmed the safety of

Table 7. Visual observations on phytotoxicity in different doses of herbicides (Scale 1 - 10)

Treatment	Epinasty						Hyponasty						Vein clearing						Wilting						Leaf injury					
	1 DAA	3 DAA	5 DAA	7 DAA	15 DAA	30 DAA	1 DAA	3 DAA	5 DAA	7 DAA	15 DAA	30 DAA	1 DAA	3 DAA	5 DAA	7 DAA	15 DAA	30 DAA	1 DAA	3 DAA	5 DAA	7 DAA	15 DAA	30 DAA	1 DAA	3 DAA	5 DAA	7 DAA	15 DAA	30 DAA
Pretilachlor 375 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pretilachlor 500 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pretilachlor 625 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pretilachlor 750 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pretilachlor 875 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pendimethalin 1000 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Butachlor 1250 g/ha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pendimethalin 1500 g/ha	0	0	1	1	2	2	0	0	1	2	2	2	0	0	1	1	1	2	0	0	1	1	2	2	0	0	1	1	2	2

Table 8. Effect of different weed control measures on economics of transplanted *Kharif* rice (pooled of two years)

Treatment	Cost of cultivation (₹/ha)	Gross return* (₹/ha)	Net return (₹/ha)	B:C
Pretilachlor 375 g/ha	46171	79388	33216	1.72
Pretilachlor 500 g/ha	46259	81975	35716	1.77
Pretilachlor 625 g/ha	46346	89340	42994	1.93
Pretilachlor 750 g/ha	46434	80805	34371	1.74
Pretilachlor 875 g/ha	46521	78030	31509	1.68
Pendimethalin 1000 g/ha	47242	72375	25133	1.53
Butachlor 1250 g/ha	46659	74985	28326	1.61
Hand weeding at 15 and 30 DAT	51709	90780	39071	1.76
Unweeded control	44209	44970	761	1.02
Pendimethalin 1500 g/ha	47909	73583	25674	1.54
LSD (p=0.05)				

*Price of rice grain and straw: ₹ 19.5/kg and ₹ 0.75/kg, respectively its use by ensuring no phytotoxic effect on crop as well as on soil health and negligible residual toxicity persistence on soil. Based on the results, post-emergence application of pretilachlor 50% EC 625 g/ ha can be recommended to rice growers of Gangetic plains of West Bengal, India for achieving high suppression of dominant weed flora and ensuring high productivity of rice as well as its follow up (*paira*) crop lathyrus.

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RESEARCH ARTICLE

Weed growth and productivity of direct-seeded rice under different weed management practices

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ABSTRACT

A field experiment was conducted during *Kharif* (rainy season), 2021 and 2022 at Agricultural Research station, Chatabar, Faculty of Agricultural Sciences, SOADU, Bhubaneswar. The soil of the experimental field was sandy loam in texture. The experiment comprising of seven treatments *viz.* pendimethalin 30 EC at 1000 g /ha, oxadiargyl 80WP at 100 g/ ha, pendimethalin PE *fb* bispyribac-sodium (1000 + 25 g/ha), oxadiargyl 80 WP PE *fb* bispyribac-sodium (100+ 25 g/ ha), bispyribac-sodium 25 g/ha, weedy check and weed free were laid out in a randomized block design with three replications. Results revealed that oxadiargyl at 100 g/ha *fb* bispyribac-sodium 25 g/ha recorded the lowest values of total weed density and weed dry weight at 45 DAS during both the years and was at par with combination of pendimethalin PE followed by bispyribac-sodium (1000+25 g/ha) PoE. The highest grain yield of direct-seeded rice along with higher yield attributing characters like number of filled grains/panicle, panicle/m^2 and test weight were recorded under weed free treatment and it was at par with oxadiargyl at 100 g/ha *fb* bispyribac-sodium 25 g/ha.

Keywords: DSR, Pendimethalin, Oxadiargyl, Weed, Grain yield

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops of the world and is the major staple food for more than half of the world's population. Weeds are most severe and widespread biological constraints to crop production in India and alone cause 33% of losses out of total losses due to pests (Verma *et al*., 2015). Weeds population is in general in direct-seeded rice than transplanted rice. Weed infestation is one of the major constraints for low productivity and causes 50-60% yield loss due to simultaneous germination of both crop and weed seeds (Pinjari *et al*. 2016). Manual weeding is considered to be the best, but it is very much costly. That is the reason why herbicides have been considered to be better alternative to hand weeding in DSR (Singh *et al*. 2006). According to Sahu and Singh (2011), chemical weed management is a good option to control weeds in direct-seeded rice. Most of the herbicides preferred for DSR are applied as pre-emergence to control weeds during initial period; however, a combination of herbicides may be more effective to control various flushes of weed. Keeping the above things in view, a field experiment was carried out to study the effect of herbicide on weed dynamics and yield of direct-seeded rice.

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MATERIALS AND METHODS

A field experiment was conducted during *Kharif* (rainy season) 2021 and 2022 at Agricultural Research station, Faculty of Agricultural Sciences, Siksha 'O' Anusandhan Deemed University (SOADU), Bhubaneswar. The soil of the experimental field was sandy loam in texture. The experiment comprising of seven treatments *viz*. pendimethalin at 1000 g/ha, Oxadiargyl 80 WP at 100 g/ha, pendimethalin PE *fb* bispyribac-sodium (1000 + 25 g/ ha) PoE, oxadiargyl (PE *fb* bispyribac-sodium (100 + 25 g/ha) PoE, bispyribac-sodium 25 g/ha PoE, weedy check and weed free, was laid out in a randomized block design with three replications. Rice variety '*MTU 1010*' was sown on 15th June 2021 and 2022 at a spacing of 20 x 15 cm. Recommended nutrient dose 80-40-40 kg/ha was aapplied. Nitrogen 80 kg/ha through urea was applied in 3 splits (one third N as basal, remaining 2/3rd in two equal split doses at active tillering and panicle initiation) and full dose of phosphorus through SSP and full dose of potash through MOP; both 40 kg/ha were applied as basal during final land preparation. In addition, zinc sulphate 25 kg/ha was applied as basal. Herbicides were applied with the help of hand operated knapsack sprayer fitted with a flat fan nozzle. All other recommended agronomic practices were followed and plant protection measures were adopted as per need. Weed counts was recorded by placing 50 x 50 cm quadrat from the marked sampling area of 1.0 m^2 in each plot and after drying them in hot air oven at 70 ^oC, weed dry weight was recorded. The data were subjected to a square root transformation to normalize their distribution. The yield components like number of panicles/m^2, grains per panicle, 1000 grain weight and yield of rice were also recorded and statistically analyzed at 5% level of significance. Weed control efficiency was calculated by using standard formula.

RESULTS AND DISCUSSION

Effect on weeds

Digitaria sanguinalis, *Echinochloa colona* among grasses, *Ludwigia parviflora*, *Hedyotis corymbosa, Lindernia ciliata, Cleome viscosa* among broad-leaved and *Cyperus iria* among sedges were predominant in the experimental field. Teja and Duary (2018) observed that *Echinochloa colona, Digitaria sanguinalis, Ludwigia parviflora* and *Sphenoclea zeylanica* were the most predominant weeds in direct-seeded rice (DSR) field. Similar types of weed flora under DSR were also reported by Chakraborti *et al.* (2018), Dhanapal *et al.* (2018), Banjara *et al.* (2019), Yadav *et al.* (2019) and Malik *et al.* (2021).

The highest density and dry weight of broad-leaved, grasses, sedges and total weed was recorded in weedy plots, whereas lowest density and dry weight was recorded in weed free plot at 45 DAS (**Table 1**). It was found that combination of oxadiargyl PE *fb* bispyribac-sodium (100+25 g/ha) PoE registered lowest density and dry weight of broad-leaved, grasses, sedges and total weed at 45 DAS and was at par with combination of pendimethalin PE *fb* bispyribac-sodium (1000+25 g/ ha) PoE (**Table 1**). The density and dry weight of total weed was reduced by 89.04 and 85.18% under oxadiargyl PE followed by bispyribac-sodium (100+25 g/ha) PoE as compared to weedy check plot.

Application of herbicide alone also performed well to control broad-leaved, grasses and sedges. Among the lonely applied herbicide bispyribac-sodium at 25 g/ha PoE was more effective in controlling weed density and dry weight of broad-leaved at 45 DAS followed by oxadiargyl at 100 g/ha PE (**Table 1**). Bispyribac-sodium at 25 g/ha PoE alone could reduce density and dry weight of BLW by 79.99 and 75.43 %, respectively as compared to weedy check plots. But pendimethalin are less effective to control broad-leaved weed. Pendimethalin was more effective in controlling grassy weeds than bispyribac-sodium. However, bispyribac-sodium was effective against grasses, sedges and broad-leaved weeds in rice fields (Walia *et al.* 2006, Yadav *et al.* 2009). The higher WCE (weed control efficiency) at 45 days was recorded in oxadiargyl PE *fb* bispyribac-sodium (100+25 g/ha) PoE treatment **(Figure 1**)

Effect on crop

Highest number of filled grains/panicle, panicles/ m^2, test weight, panicle length and grain yield were recorded under weed free treatment and it was at par with oxadiargyl at 100 g/ha PE *fb* bispyribac-sodium at 25 g/ha PoE (**Table 2**). All the weed management treatments significantly increased grain yield over unweeded control. Oxadiargyl at 100 g/ha PE *fb* bispyribac-sodium at 25 g/ha PoE and pendimethalin at 1000 g/ha PE *fb* bispyribac-sodium at 25 g/ha PoE recorded at par value of number for filled grains/ panicle, panicles/m^2, test weight and panicle length during both the years.

Among the weed management treatments, oxadiargyl at 100 g/ha PE *fb* bispyribac-sodium at 25 g/ha PoE registered significantly highest grain yield of 3.21 t/ha over other treatments and was at par with pendimethalin at 1000g/ha PE *fb* bispyribac-sodium at

Table 1. Density and dry weight of weeds in DSR under different weed management practices at 45 DAS (pooled mean)

Treatment	Weed density (no./m^2)				Weed dry weight (g/m^2)			
	BLW	Grass	Sedge	Total	BLW	Grass	Sedge	Total
Pendimethalin at 1000 g/ha	6.81(46.0)	4.54(20.3)	3.18(9.7)	8.74(76.0)	5.66(31.6)	3.83(14.4)	2.55(6.1)	7.24(52.0)
Oxadiargyl at 100 g/ha	5.23(27.0)	6.15(37.7)	2.48(5.7)	8.39(70.3)	4.62(21.1)	4.63(21.1)	2.37(5.1)	6.89(47.4)
Pendimethalin PE *fb* bispyribac-sodium (1000 + 25 g/ ha)	4.77(22.0)	4.05(16.0)	1.68(2.3)	6.38(40.3)	4.08(16.2)	3.11(9.2)	1.69(2.4)	5.33(27.9)
Oxadiargyl PE *fb* bispyribac-sodium (100+ 25 g/ ha)	4.24(17.7)	3.20(10.0)	1.87(3.0)	5.58(30.7)	3.62(12.7)	2.82(7.5)	1.66(2.3)	4.78(22.5)
Bispyribac-sodium at 25 g/ha	5.09(25.7)	6.35(40.0)	2.04(3.7)	8.34(69.3)	3.90(15.0)	5.50(29.9)	1.57(2.0)	6.87(46.9)
Weedy check	11.34(128.3)	11.65(135.3)	4.14(16.7)	16.36(280.0)	7.84(61.0)	8.87(78.6)	3.56(12.2)	12.33(151.8)
Weed free	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)
LSD (p=0.05)	0.70	1.05	0.32	0.87	0.71	0.90	0.45	0.98

Figures in parentheses are the original values. The data was transformed to SQRT (“x+0.5) before analysis

Table 2. Yield attributes and grain yield of DSR as influenced by weed management practices (pooled mean)

Treatment	Panicle length (cm)	Panicles/ m^2	1000-seed weight (g)	Filled grains/ panicle	Yield (t/ha)			Weed index (%)
					2021	2022	Pooled	
Pendimethalin at 1000 g/ha	24.83	176.63	19.37	93.53	2.04	2.25	2.15	37.89
Oxadiargyl at 100 g/ha	25.00	188.77	22.13	100.20	2.31	2.62	2.46	28.85
Pendimethalin PE *fb* bispyribac-sodium (1000 + 25 g/ha)	25.27	201.43	22.13	111.20	2.85	3.21	3.03	12.53
Oxadiargyl PE *fb* bispyribac-sodium (100+ 25 g/ha)	26.07	227.23	23.30	117.93	3.01	3.42	3.21	7.10
Bispyribac-sodium at 25 g/ha	25.12	192.00	22.30	107.20	2.46	2.81	2.63	23.88
Weedy check	21.33	155.37	18.33	79.47	1.30	1.59	1.44	58.26
Weed free	27.80	243.97	23.77	127.53	3.26	3.67	3.46	0.00
LSD (p=0.05)	2.77	33.55	2.58	16.12	0.34	0.43	0.39	

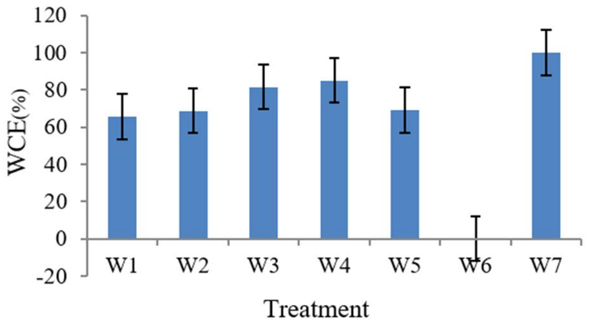

Figure 1. Weed control efficiency (%) of different weed management practices at 45 DAS in DSR

W$_1$- pendimethalin at 1000 g /ha, **W$_2$**- oxadiargyl (topstar 80 WP) at 1000 g /ha, **W$_3$**- pendimethalin PE (stomp 30 EC) *fb* bispyribac-sodium (nominee gold 10 SC) (1000 + 25 g /ha), **W$_4$**- oxadiargyl (topstar 80 WP)PE *fb* bispyribac-sodium (nominee Gold 10 SC) (1000 + 25 g /ha), **W$_5$**- bispyribac-sodium (nominee gold 10 SC) 25 g /ha, **W$_6$**- weedy check and **W$_7$**- weed free

25 g/ha PoE (**Table 2**). Oxadiargyl at 100g/ha *fb* bispyribac-sodium at 25 g/ha recorded 30.51 and 49.53% higher grain yield as compared to application of oxadiargyl alone and pendimethalin, respectively. These results were in accordance with Dhanpal *et al.* (2018) and Singh and Pairka (2014). Though weed free check registered significantly the highest grain yield of 3462 kg/ha of direct-seeded rice, it was comparable with oxadiargyl at 100 g/ha PE *fb* bispyribac-sodium at 25 g/ha PoE treatment.

Weed index (%) was calculated on the basis of grain yield and all the weed management practices recorded lower weed index (WI) compared to weedy check (**Table 2**). The lowest value of WI was recorded with oxadiargyl at 100 g/ha PE *fb*

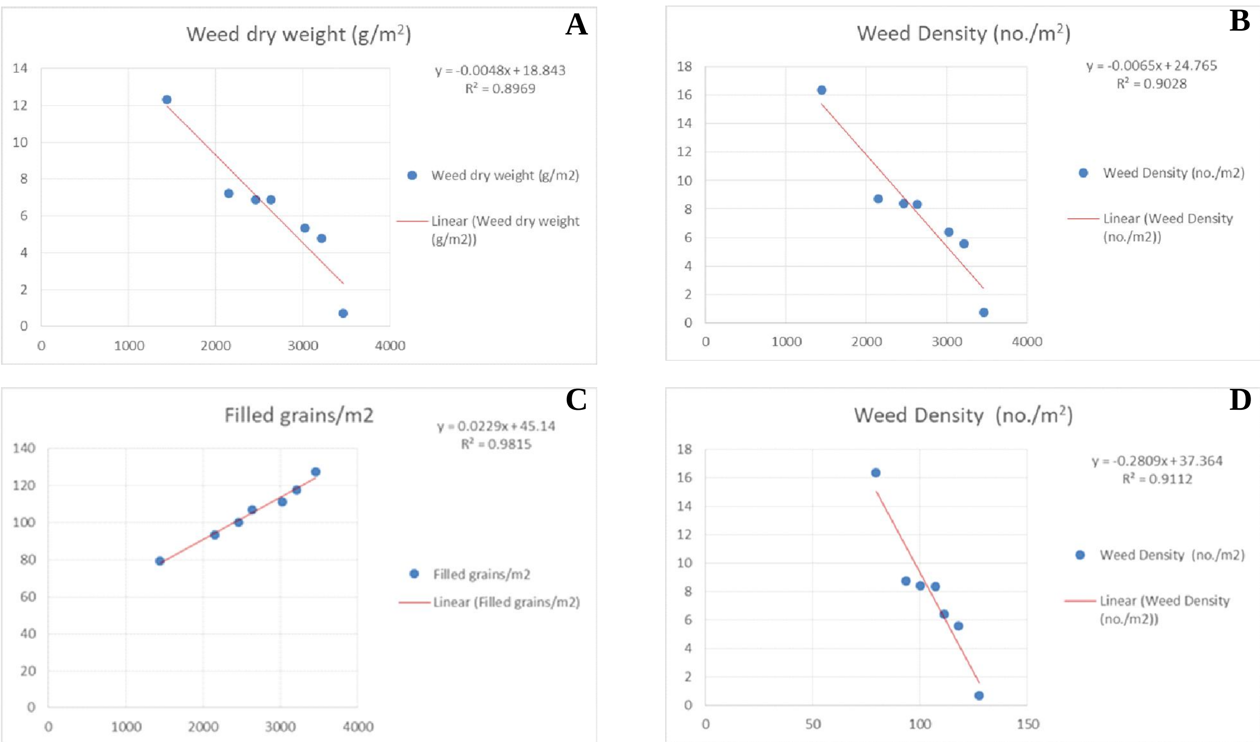

Figure 2. Relationship between (a) grain yield and weed dry weight; (b) grain yield and weed density; (c) yield and number of filled grains/ panicle; and (d) weed density and number of filled grains/ panicle as affected by different integrated weed management practices

Table 3. Pearson's correlation matrix among the weed density and dry weight at 45 days after application of herbicides and yield components

	Weed density	Weed dry weight	Panicle length	No. of panicles	1000-seed wt.	Filled grains	Yield	Weed index
Weed density	1							
Weed dry weight	0.9976	1						
Panicle length	-0.9921	-0.9841	1					
No. of panicles	-0.9373	-0.9469	0.9202	1				
1000-seed wt.	-0.8703	-0.8658	0.8753	0.9107	1			
Filled grains	-0.9545	-0.9570	0.9408	0.9782	0.9464	1		
Yield	-0.9501	-0.9470	0.9341	0.9605	0.9447	0.9907	1	
Weed index	0.9500	0.9469	-0.9340	-0.9605	-0.9447	-0.9907	-1	1

bispyribac-sodium at 25 g/ha PoE treatment this was followed by pendimethalin at 1000g/ha PE *fb* bispyribac-sodium at 25 g/ha PoE. The highest weed index was recorded under weedy check (58.26%).

Correlation and regression analysis

The weed density and dry matter had highly significant negative correlation with the yield attributes and yield of rice in both the years (**Table 3** and **Figure 2a, b, d**). However, the yield attributes like panicle length, number of panicles per m^2 and filled grains per m^2 were positively correlated with yield (**Table 3** and **Figure 2.c**). It implies that yield attributes and yield of rice decreased with proportional increase in weed interference and vice-versa. Similar negative correlation between weeds and crop was reported by Ganai *et al*. (2014), who stated that higher weed density and weed dry weight caused significant reductions in yield attributes which in turn reduced the crop yield significantly.

It was concluded that integrated use of pre-emergence herbicide oxadiargyl at 100g/ ha *fb* bispyribac-sodium at 25 g/ha PoE found to be promising for effective weed management in direct-seeded rice under Odisha conditions of India.

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RESEARCH ARTICLE

Impact of crop establishment on major weeds and their vertical distribution in rice

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ABSTRACT

Weed management strategies across diverse cropping systems must address weed seed distribution and emergence behaviour. Various agronomic practices, including tillage, have been documented to influence these factors, thus assuming a critical role in the formulation of weed management strategies. In a study during the rainy (*Kharif*) seasons of 2021 and 2022, the impact of different crop establishment methods: puddled transplanted rice (PuTTR); direct-seeded rice on permanent beds (PBDSR)-with residue (+R); zero till direct-seeded rice (ZTDSR)+R/-R; ZTDSR with inversion (+I)+R/-R; unpuddled transplanted rice (UPTR); (+R); (R) on the vertical spatial distribution of weed seeds within the soil and the emergence dynamics of distinct weed species was systematically assessed. The results unveiled that vertical distribution in PBDSR+R and ZTR +R/-R had 84% of beads (simulated weed seeds) in 0-3 cm and 16% in 3-6 cm. None of the beads were found in the lower depth of lesser disturbed soil. In contrast, conventional tillage (PuTTR and UPTR) had higher soil disturbance resulting in only 12.75% and 22.5% beads on top layer (0-3 cm) and 19.4 % and 34.5 % in 3-6 cm, 36.16 % and 24.8 % in 6-9 cm, 28 % and 14.3% in 9-12 cm, respectively. PuTTR and UPTR systems reduce the weed incidence by bury the high proportion of weed seeds below 3 cm. Furthermore, the study delineated that the maximal seedling emergence of *Leptochloa cheninsis, Ammannia baccifera, Echinochloa crus-galli* and *Caesulia axillaris* in ZT without residue followed by ZT+R. R egardless of weed species, the average emergence was 14%. The minimal germination of weeds was in PuTTR and UPTR. This investigation furnishes invaluable insights that may inform judicious decision-making in the realm of weed management, with an emphasis on the judicious integration of tillage methodologies and complementary weed control measures.

Keywords: *Ammannia baccifera,* Crop establishment, *Echinochloa crus-galli, Leptochloa chinensis,* Vertical distribution, Weed emergence pattern

INTRODUCTION

Rice is a staple food in many parts of India and is a significant component of the Indian diet. Conventional puddled rice was more common in India. However, conventional practices are associated with several drawbacks. Input costs rise, putting farmers under financial strain, mainly due to tillage and high labour cost for manual transplanting. Furthermore, these practices delay the subsequent wheat sowing process. A further disadvantage of conventional farming practices is to disrupt the natural state of the soil, thereby creating an unfavorable physical environment that hampers the growth and development of the following wheat crop (Dhanda *et al.* 2022). Disturbed soil conditions become a significant impediment to wheat cultivation, preventing it from progressing smoothly. But, presence of standing water during crop establishment, which suppresses weed growth. In contrast, direct-seeded rice (DSR) production is hindered by the presence of weeds and because of cultivated crops and weeds are not distinguished by distinct size variations, effective differentiation is difficult (Chauhan 2012, Hossain *et al.* 2020). However, direct seeding with dry seed, especially under ZT has numerous benefits, including reducing soil erosion, improving soil properties, conserving soil moisture and reduce fuel costs (Chauhan *et al.* 2012, Chaudhary *et al.* 2022). DSR systems had gained wide adoption among Indian farmers. DSR systems also increase crop yields, reduce the need for chemical fertilizers and improve water availability (ADB 2019). Furthermore, this technology helps to improve air quality and reduce greenhouse gas emissions (Pathak *et al.* 2013, de Araújo Santos *et al.* 2019).

This changes in tillage practices, however, can affect weed seed vertical distribution in the soil, thereby affecting weed species abundance. A

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significant portion of the weed seed bank found in ZT systems remains near the soil surface, resulting in predominance of light-dependent weed species such as *Leptochloa chinensis, Ammannia baccifera and Echinochloa crus-galli* (Singh *et al.* 2016, Yadav *et al.* 2018, Padmakumari *et al.* 2019, Hossain *et al.* 2020). As an alternative, conventional tillage may favour the growth of weed species that can tolerate deeper burial depths. This could change the composition of the weed seed bank. A limited knowledge available on weed emergence of *Leptochloa chinensis, Ammannia baccifera, Caesulia axillaris and Echinochloa crus-galli* in both conventional and DSR. Research is essential to understand the impacts of reduced tillage on weed species. Our study's aim was to investigate how different establishment method influence weed emergence pattern and changes in the vertical weed distribution. This helps to understand the germination ecology, ultimately in decision making for early weed management.

MATERIALS AND METHODS

Field investigations were conducted in 2021 and 2022 growing seasons in ongoing (since 2006) experiment "Long-term Research on Conservation Agriculture in a Rice-Wheat Cropping System of Eastern Indo-Gangetic Plains" by CIMMYT at Research farm in Dr. Rajendra Prasad Central Agricultural University, Pusa situated in North of Bihar, India. The research evaluated different type of crop establishment method listed in **Table 1**. Composite sample was taken before initiating the experiment, soil pH, electrical conductivity (EC) and organic carbon (OC) was 8.53, 0.58 dS/m and 0.72%. Primary available nutrients in soil were N (210 kg/ha), P (12.29 kg/ha) and K (129.41 kg/ha). The annual rainfall received during rice cultivation was 1592 mm and 675 mm in 2021 and 2022, respectively.

For seedling emergence pattern

The rice from major weeds taken for study, *viz. Ammannia baccifera, Caesulia axillaris, Echinochloa crusgalli, Leptochloa chinensis*. All the weed seeds collected from mature plants from Research farm, RPCAU, Pusa. Collected seeds were stored at room temperature. Selected weed Seeds (@100/m^2) were spread evenly 3 months before initiating tillage for rice crop in 2 m x 2 m plot size, and with subsequent seedlings emerging after crop sowing were observed at 7 days interval up to 56 days. Rice sowing was also done on which emergence of weed had been studied. However, the other species weeds were allowed to grow in the sampling area. Additionally, control plots were established in both years without introducing seeds of weeds, and seedling emergence was measured to determine the natural seed bank. Data presented in emergence rate after subtracting the control plot and expressed in the percentage of emergence.

For vertical seed (plastic beads) distribution

Plastic beads (1.5 mm x 1 mm) serving as proxies for weed seeds, were uniformly scattered in 2 x 2 m area 100/m^{-2} just before of tillage were employed to evaluate the influence of tillage on the vertical distribution of seeds within the soil. The crop establishment methods adopted during rice crop season in different treatments was explain in detail under **Table 1**. After planting, soil sampled and washed with water to separate and count the distribution at different depth (*i.e.* 0-3 cm, 3-6 cm, 6-9 cm and 9-12 cm) and presented as a percentage relative to the total bead count across all depths.

Table 1. Treatment details

Treatment	Tillage	Crop establishment	Residue management
PuTTR–CTW	3 passes of dry tillage with harrow, 2 passes of cultivator in ponded water followed by 1 planking	Manually transplanted, random geometry	All removed
PuTTR–ZTW	3 passes of dry tillage with harrow, 2 passes of cultivator in ponded water followed by 1 planking	Manually transplanted, random geometry	All removed
PBDSR–PBDDW (+R)	Zero till	Direct dry seeding on permanent beds	50% rice residue retained in wheat cycle
ZTR–ZTW	Zero till	Direct dry seeding on flat soil, row geometry	All removed
ZTR- ZTW-R (+I)	Zero till	Direct dry seeding on flat soil, row geometry	All removed
ZTR- ZTW+R (+I)	Zero till	Direct dry seeding on flat soil, row geometry	50% rice residue retained
UPTR-ZTW	3 passes of dry tillage with harrow, 1 pass of cultivator followed by 1 planking	Manually transplanted, random geometry	All removed
ZTR (+SBM)- ZTW	Zero till	Direct dry seeding on flat soil, row geometry	All removed

Statistical analysis

A two-way ANOVA was used in order to analyse vertical seed distribution across different tillage systems based on a randomized block design, which consisted of incorporating tillage as a factor and depth as the other, using the SigmaPlot 15.0 statistical software package. Due to the presence of different significant time (DAS) in the different year, the results for each year of the study were analyzed individually in order to determine when seedling emergence was influenced by different tillage systems at each sampling time (DAS). An application of SigmaPlot 15.0 software was used to implement a functional three-parameter sigmoid model of seedling emergence for each species, under varying tillage systems. The model, which was applied to SigmaPlot 15.0 software, was expressed as follows:

$$E\ (\%) = E_{max} / (1 + \exp((x - T_{50}) / E_{rate})) \quad ....1$$

In this equation, E represents the total seedling emergence (%) at time x, E_{max} represents the highest percentage of seedling emergence ever recorded (%), T_{50} represents the time required (in days) to obtain 50% emergence, and E_{rate} represents the slope around T_{50}.

RESULTS AND DISCUSSION

Seedling emergence pattern

Caesulia axillaris: The size of the seed has a significant impact on the germination from depth. This may positively affect germination in this species since most of seeds remain on top of the soil surface under ZTR conditions. After 21 days in 2021 and 14 days in 2022, seedling recruitment of pink node flower (*Caesulia axillaris*) after ZTR approached (with or without residue) was significantly higher (P>0.05) in comparison to transplanted plots till 56 days in both years (**Figure 1a**). As compared to ZT with residue (3-8%) or without residue (10-13%), the Sigmoid fitted model (Equation 1) estimated lower recruitment under transplanted system (2-3%) in both years. In the PuTTR and UPTR, 50% of seedlings emerged within a shorter timeframe (T_{50}) (**Table 2**). While seedling recruitment rate (E_{rate}) varied across systems, it was strikingly similar.

Pink node flower seeds require almost equal periods of imbibition, which could equalize germination rates. Singh and Amritphale (1992) stated that *Caesulia axillaris* require 5 days for imbibition. Singh and Amritphale (1992), demonstrated that there is absolute requirement of light for germination, resulting in a 50% reduction in residue presence compared with absence of crop residue over surface.

***Echinochloa crus-galli*:** The cumulative emergence of *E. crus-galli* seedlings was significantly higher under zero-tillage (ZT) rice during both observation years (P<0.05). Puddled transplanted rice (PuTTR) and unpuddled transplanted rice (UPTR) displayed significantly higher emergence rates around T_{50} than ZTDSR with or without residue (**Figure 1b**). However, peak seedling emergence varied, with 20% to 24% of initially sown seeds emerging under ZTR (-R), 10% to 12% emerging under crop residue (PBDSR+R and ZTDSR +R), and 2% to 6% emerging under transplanted rice (**Table 3**). Transplanted system (Puddled and Unpuddled) had achieved T_{50} at least 3 days earlier than no till system.

This heightened seedling emergence experienced under ZT can likely be attributed to the comparatively smaller size of *E. crus-galli* seeds (**Table 3**). The diminutive seed size rendered them incapable of emerging from deeper burial caused by UPTR and PuTTR practices. Greater depth reduces the seedling emergence as observed in other weed specie *i.e Rumex obtusifolius*, there was no germination below 8 cm (Benvenuti *et al.* 2001a). In the ZTW(+R) and PPDSR (+R), however, there may be less emergence because there is less light which inhibit seedling emergence. Similar observations have been made in other weed species, where the emergence of seeds buried deeply is inversely correlated with their weight (Benvenuti *et al.* 2001b).

***Ammannia baccifera*:** Emergence pattern of *A. baccifera* was found significantly higher throughout study period in ZTR than transplanted system. Blisteting ammania seeds were very tiny with a test weight of 0.0198g (**Table 4**). So, Emergence was limited to 1% in PuTTR and UPTR whereas, 5-6% seedling recruitment in the ZTR (+R) and PBDSR (+R) and 12-17% emergence in 2021 (**Figure 1c**). 3 parameter sigmoid fit model had given lesser E_{rate} for transplanted system than DSR approach. T_{50} in the ZTR (+R) and PBDSR (+R) were lower than other system (**Table 4**).

Crop residue inhibits light reaching on the surface resulting lesser seed emergence even though larger number of seed remains on the surface. Crop residue inhibits light reaching the surface, which results in lesser seed emergence (Sepat *et al.* 2017; Jat *et al.* 2019), despite the presence of a larger number of seeds on the surface. This might be due to the fact that light-induced inhibition of germination has been documented in a closely related species, *Ammannia coccinnea*, as noted by Gibson *et al.* (2001). Furthermore, Shen *et al.* (2010) showed more emergence at shallower depths of 3 cm and

Table 2. Responses of *Caesulia axillaris* to seedling emergence under different crop establishment method

Crop establishment method	2021				2022			
	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
PuTTR- CTW	1.7(0.04)	4.4(0.7)	19.9(0.6)	0.99	2.2(0.3)	10.7(4.1)	29.7(2.8)	0.96
PuTTR- ZTW	1.7(0)	4.5(0.6)	22.3(0.5)	0.99	2.6(0.3)	9.2(2.9)	30(2.1)	0.97
PBDSR-PBDDW (+R)	5.9(0.2)	4.4(0.9)	20(0.8)	0.98	7.8(0.6)	9.6(2.1)	37.4(1.2)	0.99
ZTR- ZTW	10.4(0.5)	6(1.2)	26.8(1)	0.98	12.1(0.9)	9.5(2.2)	29.9(1.5)	0.98
ZTR- ZTW-(I)(-R)	12.7(0.4)	6.2(0.9)	28.7(0.7)	0.99	12.9(0.9)	9(2.1)	29(1.5)	0.98
ZTR- ZTW-(I)(+R)	4.8(0.1)	4.6(0.8)	22.8(0.7)	0.99	5.2(0.6)	10.8(3.8)	32.1(2.4)	0.97
UPTR- ZTW	3.4(0.1)	2.6(0.4)	23(0.3)	0.99	2(0)	5.8(0.7)	24.8(0.6)	0.99
ZTR (+SBM) – ZTW	12.6(0.6)	7.6(1.2)	31.2(0.9)	0.99	11.7(0.6)	8.4(1.4)	30.7(1)	0.99

Table 3. Responses of *Echinochloa crus-galli* to seedling emergence in different crop establishment method

Crop establishment method	2021				2022			
	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
PuTTR- CTW	5.2(0.3)	5.6(1.5)	21.8(1.3)	0.971	6.3(0.03)	2.3(0.1)	15.9(0.1)	0.99
PuTTR- ZTW	4.4(0.4)	8.8(2.5)	25.3(2)	0.968	5.9(0.1)	2.9(0.5)	16.1(0.4)	0.99
PBDSR-PBDDW (+R)	11.8(0.1)	4.4(0.3)	13.9(0.3)	0.996	12.4(0.1)	3.3(0.3)	11.7(0.3)	0.99
ZTR- ZTW	23.2(0.8)	7.5(1.1)	15.4(1.2)	0.98	20.2(0.1)	3.2(0.1)	11.7(0.1)	0.95
ZTR- ZTW-(I)(-R)	24(0.4)	6.7(0.6)	14.6(0.6)	0.992	22.2(0.1)	4.1(0.2)	14(0.2)	0.98
ZTR- ZTW-(I)(+R)	10.9(0.2)	4.3(0.5)	15.5(0.5)	0.993	10.4(0.04)	2.6(0.1)	11.3(0.1)	0.99
UPTR- ZTW	6.1(0.5)	8.8(2.6)	27.1(2)	0.969	6.7(0.1)	3.7(0.4)	17.6(0.3)	0.99
ZTR (+SBM) – ZTW	26.3(0.9)	7.5(1.1)	20.8(1)	0.987	24(0.5)	4.4(0.7)	14.2(0.6)	0.99

Table 4. Responses of *Ammannia baccifera* to seedling emergence under different crop establishment method

Crop establishment method	2021				2022			
	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
PuTTR- CTW	0.7(0)	0.4(0)	14(0)	1	1.3(0)	0.4(0)	14(0)	1
PuTTR- ZTW	0.3(0)	0.3(0.2)	10.6(0)	1	0.7(0)	0.4(0)	7(0)	1
PBDSR-PBDDW (+R)	5.1(0)	7.5(0.4)	8.4(0.5)	0.99	6.3(0)	2.9(0.2)	9.2(0.2)	0.99
ZTR- ZTW	12.1(0.2)	6(0.6)	15.3(0.6)	0.99	14.4(0)	2.9(0.1)	14.7(0.1)	0.99
ZTR- ZTW-(I)(-R)	13(0.2)	4.5(0.4)	13.7(0.3)	0.99	17.5(0.3)	5(0.6)	16.2(0.5)	0.99
ZTR- ZTW-(I)(+R)	4.3(0)	3.2(0.1)	8.5(0.1)	0.99	5.4(0)	3.1(0.1)	9.5(0.1)	0.99
UPTR- ZTW	0.7(0)	0.4(0)	14(0)	1	1(0)	0.6(0)	13.6(0)	1
ZTR (+SBM) – ZTW	12.9(0.1)	3.3(0.3)	13.4(0.3)	0.99	16.8(0.2)	4.5(0.4)	13(0.4)	0.99

Table 5. Responses of *Leptochloa chinensis* to seedling emergence in different crop establishment method

Crop establishment method	2021				2022			
	E_{max}	E_{rate}	T_{50}	R^2	E_{max}	E_{rate}	T_{50}	R^2
PuTTR- CTW	4.7(0)	0.5(0.02)	20.5(0.02)	1	2.3(0)	0.5(0)	20.5(0)	1
PuTTR- ZTW	3.3(0.1)	2.2(0.5)	15.8(0.4)	0.99	2.3(0)	0.5(0)	20.1(0)	1
PBDSR-PBDDW (+R)	12.8(0.2)	3.5(0.5)	12.4(0.5)	9.98	9.8(0.1)	4.5(0.5)	8.9(0.6)	0.98
ZTR- ZTW	18.2(0.1)	2.7(0.2)	9.3(0.2)	0.99	22.7(0.1)	3.3(0.1)	12.2(0.1)	0.99
ZTR- ZTW-(I)(-R)	19.2(0.2)	2.9(0.2)	10.2(0.2)	0.99	21.8(0.2)	3.4(0.3)	12.1(0.3)	0.99
ZTR- ZTW-(I)(+R)	8.6(0.1)	2.1(0.3)	10.4(0.2)	0.99	8.4(0.1)	3.8(0.3)	16.4(0.2)	0.99
UPTR- ZTW	6.4(0.1)	3.7(0.3)	15.2(0.3)	0.99	7.4(0.1)	2.4(0.2)	20.5(0.3)	0.99
ZTR (+SBM) – ZTW	21.7(0.03)	3.3(0.04)	11.3(0.03)	0.99	19.9(0.4)	3.6(0.6)	12.5(0.5)	0.98

Standard error (SE) is included with parameter estimates in parenthesis. A three-parameter sigmoid model was fitted to the seeding emergence data. $\mathbf{E_{max}}$ is the maximum seedling emergence (%), $\mathbf{E_{rate}}$ denotes slope around T_{50} and $\mathbf{T_{50}}$ is the time (days) to reach 50% of maximum seedling

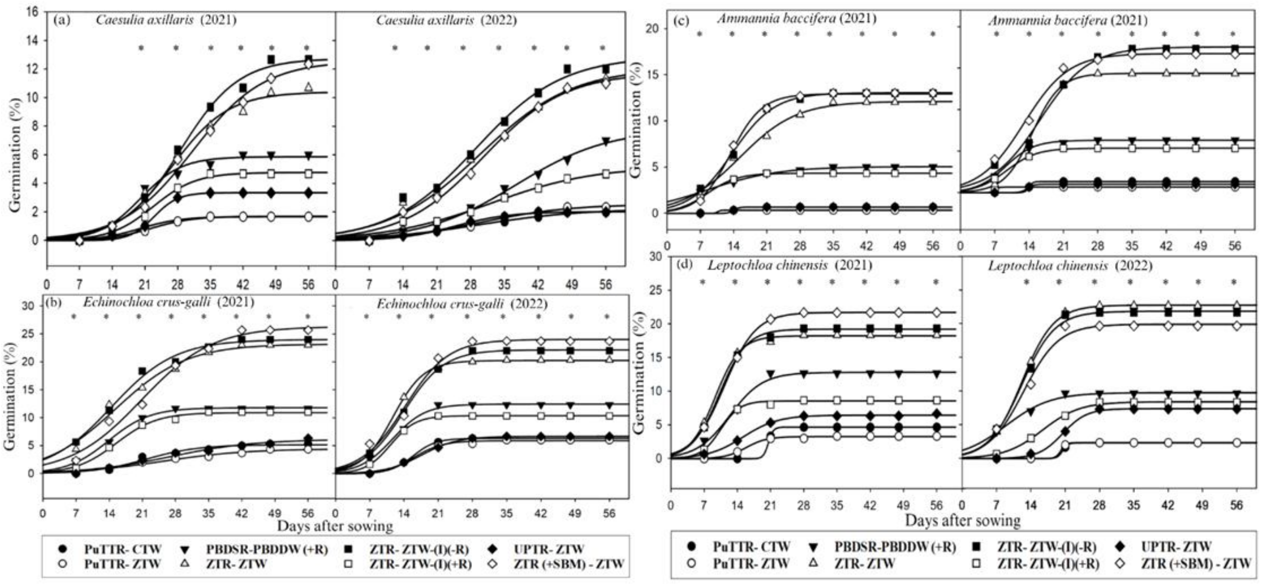

Figure 1. Seedling emergence pattern of (a) *Caesulia axillaris*, (b) *Echinochloa crus-galli* (c) *Ammannia baccifera* and (d) *Leptochloa chinensis* in different crop establishment method; The asterisk was used to indicate significant differences among different crop establishment method was observed (p < 0.05).

conforming to its photoblastic nature. DSR allowed *A. baccifera* germinate and establish more rapidly due to the fact that conserve moisture and seed remain on surface in the field.

***Leptochloa chinensis*:** The results of our study showed that plots subjected to the ZTR approach displayed significantly higher levels of seedling recruitment for the *Leptochloa chinensis* than plots subjected to the PuTTR or UPTR approach during both years of our investigation (as shown in **Figure 1d**). There was a maximum of 18-23% of seedling recruitment in ZTR(-R) plots for the years 2021 and 2022, contrasting with 9-13% and 2-7% in ZT with residue (PBDSR+R, ZTDSR+R) plots and transplanting plots (PuTTR or UPTR) plots (**Table 5**). The increased burial depth within the more disturbed plot (PuTTR and UPTR) could contribute to a longer time period required to reach the T_{50} (15-20 days) value in comparison to the less disturbed plot (ZTR) system (**Table 5**).

The higher seedling recruitment observed under ZTR may be due to the fact that there are the higher seed residues on the surface (Chauhan and Johnson 2009) in combination with the stimulation caused by exposure to light and higher temperature fluctuation (Benvenuti *et al.* 2004). On the other hand, puddled and unpuddled soil had lesser germination due to the higher percentage of seeds buried, higher than 0.5 cm, incapable of receiving light more than 1% (Chauhan and Johnson 2008), to a greater depth. Aulakh *et al.* (2006) had also confirmed the validity of this conjecture, claiming that seeds placed deeper

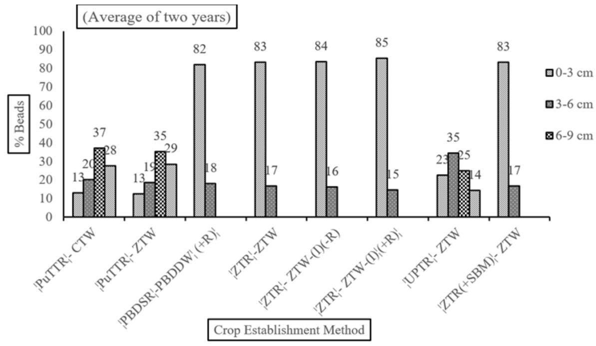

Figure 2. Vertical distribution of weed seeds as affected by crop establishment methods

than 2.5 cm did not emerge to the surface. Another, *Leptochloa fusca*, a diploid closely related species (Farooq 1989) had reduced germination in absence of light (Altop *et al.* 2015).

Vertical seed distribution influences by crop establishment method

Vertical distribution was not found significant under different tillage system. However, vertical distribution of beads found significant (P<0.001) with respect to soil depth and interaction between tillage practices and depth. The tillage with lesser disturbance with PBDDR+R and ZTR+R or without residue (ZTR) had 84% of beads in 0-3cm and 16% in 3-6 cm. None of the beads were found in the lower depth of lesser disturbed soil. In contrast, conventional tillage (PuTTR and UPTR) resulted in higher soil disturbance resulting in only 12.75% and 22.5% beads on top layer (0-3 cm) and 19.4% and 34.5% in 3-6 cm, 36.16% and 24.8% in 6-9 cm, 28% and 14.3% in 9-12 cm, respectively (**Figure 2**).

Depending on the species, there are differences in the weed seed size, seed weight, and other morphological characteristics that influence the burial process of the weed seeds (Chauhan and Johnson 2009). Weed seedling emergence patterns are largely determined by how seeds are distributed vertically in soil as a consequence of different tillage methods (Chauhan *et al.*2006). As a result of soil tillage, seeds are placed differently within soil layers, which then affects the emergence pattern of weed seedlings and the overall weed population. Use of plastic beads for stimulating the weed seeds might not give the most accurate description of the seed distribution of the weed seeds. There is no doubt that stimulation can explain the system with less interference resulted in a greater portion of weed seeds near the soil surface than those that were buried. Above ground seeds more likely subjected to predation or loose viability early due to high weather fluctuation. But conventional tillage helps to weed seed buried and continued to persist for a longer period of time or, thus becoming a part of the long-term weed seed bank.

Conclusion

Based on the results of this study, it may be possible to develop models and determine optimal weed control timings within crops. Regardless of the type of tillage system used or the weed species present, the maximum seedling emergence observed was 14%. In ZT systems as well as in permanent bed systems, weeds appear to be promoted, suggesting that they may become a significant problem. Therefore, management strategies may be needed to address this issue. Alternatively, adopting PuTTR and UPTR methods might be effective in slowing down the buildup of weed populations. Weed seedling emergence patterns are largely determined by how seeds are distributed vertically in soil as a consequence of different tillage methods. PuTTR and UPTR helps to bury weed seeds in greater depth while, PBDSR and DSR keep close to the soil surface. These result raises important questions about the fate of seeds remaining in the seed bank when seedling emergence is limited. Do these seeds decompose before the start of the next growing season, or do they become part of a more persistent seed bank? Further research is required to address this crucial knowledge gap in our understanding of the ecology of these weed species.

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RESEARCH ARTICLE

Management of jungle rice *(Echinochloa colona)* through herbicides in transplanted rice

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ABSTRACT

Field experiments were conducted to select suitable pre- and post-emergence herbicides for the control of *Echinochloa colonum* in rice. Treatments consisted of herbicide, *viz.* unweeded control, two hand weeding at 20 and 40 DAT/DAS, (PE) application of premixed pretilachlor 6% + bensulfuron-ethyl 0.6% GR 10 kg /ha at 3 DAT + hand weeding on 40 DAT/DAS, (PE) application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl 0.15% GR 10 kg/ha at 3 DAT + hand weeding on 40 DAT/DAS, (PE) application of pre-mixed pretilachlor 6% + bensulfuron-ethyl 0.6% GR 10 kg/ha at 3 DAT with PoE application of bispyribac-sodium 10% SC 200 mL/ha on 20 DAT, (PE) application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl 0.15% GR 10 kg/ha at 3 DAT with PoE application of bispyribac-sodium 10% SC 200 mL/ha on 20 DAT. Significantly lesser weed density (66.4/m^2), dry weight (80.8 g/m^2) and higher weed control efficiency (82.9%) were recorded with PE application of premixed pretilachlor 6% + bensulfuron-methyl 10 kg/ha at 3 DAT + PoE application of herbicide bispyribac-sodium 10% SC 200 mL /ha on 20 DAT than other treatments at 45 DAT. Significantly higher dry matter production (6.10 t/ha), more number of productive tillers (382/m^2) and filled grain/panicle (173) higher grain yield of 5.68 t/ha, mean net returns (₹ 50475/ha) and benefit cost ratio of 2.52 were recorded in PE application of pre-mixed pretilachlor + bensulfuron-methyl 10 kg/ha on 3 DAT + PoE application of herbicide bispyribac-sodium 200 mL /ha on 20 DAT than other treatments. Thus, it could be concluded that PE application of pre-mixed pretilachlor + bensulfuron-methyl 10 kg/ha on 3 DAT + PoE application of herbicide bispyribac-sodium 200 mL/ha on 20 DAT controlled the *Echinochloa colona* effectively and produced higher productivity and profitability of rice in transplanted condition.

Keywords: Bensulfuron-methyl, Bispyribac-sodium, *Echinochloa colonum*, Pretilachlor, Pyrazosulfuron-ethyl

INTRODUCTION

Jungle rice (*Echinochloa colonum*) belongs to the Gramineae family and is a type of wild annual grass, up to 60 cm tall, with reddish purple or green stem, ascending to erect without hairs and long narrow spiny leaves. It is widely distributed in India, Bangladesh, Cambodia, Nepal, Pakistan, Thailand and Vietnam. Its infestation is very common in various crops, such as rice, maize, vegetables and legume crops. It is very problematic weed in irrigated rice and complete crop failure has been observed because of this weed (Mahajan and Chauhan 2022). The menace due to weeds is higher as the weeds emerge before or simultaneously with the crop emergence and this in turn brings down the final grain yield. The losses of grain yield due to weeds in rice crop ranges from 20 to 60 per cent and 30 to 80 per cent in transplanted and direct-seeded rice, respectively (Gharde *et al*. 2018). In rice cultivation, the management of the weeds at early stage of crop emergence is the most important requisite for profitable rice production. Hand weeding is most effective traditional method of eradication of weeds. However, the prevailing labour in availability and escalated labour wages for agricultural operations make this operation uneconomic. Under this condition, chemical method of weed control is an effective, economical and time saving strategy to combat the weeds. Besides the cost-effective nature it requires only minimal labour, curtails weed competition and augments crop productivity.

Although several ready-mix pre-emergence herbicides are available with high phytotoxicity on weeds, its potentiality against weeds needs to be ascertained through field experimentations. On other hand, the continuous use of similar type herbicides results in developments of resistance, leads to shift in weed flora orienting towards the weed species which are sparse in rice ecosystem. Different types of newer molecules of pre-emergence and post-emergence herbicides are available, bensulfuron methyl and pyrazosulfuron ethyl under systemic pre-emergence herbicidal group and the bispyribac sodium of post-emergence category, for managing of

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weeds in rice crop. The sequential application of pre-mixed pre-emergence herbicides followed by post-emergence herbicides could be more effective in the control of wider spectrum of weeds of rice (Parameswari and Srinivas (2017). Keeping in this view, field experiments were conducted to study the effect of PE and PoE herbicides on control of *Echinochloa colonum* under transplanted rice.

MATERIALS AND METHODS

A field experiment was conducted at Experimental Farm, School of Agriculture, Bharath Institute of Higher Education and Research, Selaiyur, Tamil Nadu, India during *Kharif* (rainy season) 2022 and 2023 to study the management of *Echinochloa colonum* through herbicides in transplanted rice. The study area has mean annual rainfall of about 1500 mm, majority of which was received during North-East Monsoon. The climate of the region is characterized by a tropical climate with a hot dry period (March-May), and extended wet period from November to February. The soil of the experimental field was moderately drained, clayey loam texture soil and soil is medium available in nitrogen (201.39 kg ha), high available in phosphorus (20.57 kg ha) and potassium (280.53 kg ha) with a pH of 7.4.

The experiment was laid out in a RBD (randomized block design) with three replications. Treatments consisted of herbicide, *viz*. unweeded control, two hand weeding at 20 and 40 DAT/DAS, (PE) application of pre-mixed pretilachlor 6% + bensulfuron-ethyl 0.6% GR 10 kg/ha at 3 DAT + hand weeding on 40 DAT/DAS, (PE) application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl 0.15% GR10 kg/ha at 3 DAT + hand weeding on 40 DAT/DAS, (PE) application of pre-mixed pretilachlor 6% + bensulfuron-ethyl 0.6% GR 10 kg /ha at 3 DAT with PoE application of bispyribac-sodium 10% SC 200 mL/ha on 20 DAT, (PE) application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl 0.15% GR10 kg/ha at 3 DAT with PoE application of bispyribac-sodium 10% SC 200 mL/ha on 20 DAT. Rice variety '*CO 51*' was used for this study. The plot size of experiment was 5 × 4 m. Recommended seed rate (40 kg/ha) was used for nursery were treated with carbendazim 2 g/kg of seeds and soaked in water for 10 hrs and 15 × 10 cm spacing is adopted for transplant the seedlings. Twenty days old nursery was used in transplanting. A fertilizer dose of 120 : 40: 40 NPK kg/ha was adopted for the experiment. Full dose of phosphorous and half dose of nitrogen and potassium were applied as basal. The remaining half dose of nitrogen and potassium were applied into two splits during maximum tillering and panicle primordium initiation (PPI) stage. Nitrogen, phosphorous and potassium were supplied through urea, single super phosphate, and muriate of potash respectively. As per the treatment schedule, required quantity of herbicides was sprayed. The pre-emergence and post-emergence herbicide were sprayed with high volume Knapsack sprayer fitted with flood jet nozzle using 500 liters of water ha^{-1}. Pre-emergence herbicide pretilachlor 6% + bensulfuron methyl 0.6% GR and pretilachlor 6% + pyrazosulfuron-ethyl 0.15 % GR was sprayed on 3 DAT and post-emergence herbicides bispyribac sodium was sprayed on 20 DAT. A thin film of water was maintained at the time of both liquid and granular herbicide application. Observation on yield attributing characters, grain yield of rice, weed density, weed dry weight were recorded. The number of tillers were counted in the five hills earmarked at random and the mean value was recorded as number/hill. The number of panicles/m^2 was conducted from the sample hills at the time of harvest and the mean value were recorded. The panicles were randomly chosen for recording number of filled grains/panicle. The differentiation of well filled and chaffy grains was made by pressing the grain with fingers and they are counted and recorded. Weed population was recorded by using four quadrants of 0.25/m^2 area placed at random in each of the net plot area and computed to total weeds/m^2. Prior to transplanting the weed species present in the unweeded plots were identified and grouped in to grasses, sedges and broad-leaved weeds. Weed control efficiency was worked out at 45 DAS during both years and expressed as the percentage. The gross and net income/ha for each treatment was worked out based on the prevailing market rates. The net income was calculated by deducting the cost of cultivation from the gross return. Return/rupee invested was worked out by dividing the gross return by the cost of cultivation. All recorded data were analyzed statistically as per the method suggested by Panse and Sukhatme (1978).

RESULTS AND DISCUSSION

Effect on weeds

Commonly, grasses and sedges are the most dominant weeds in transplanted rice cultivation. Predominant grassy weeds present in the transplanted rice field were *Echinochloa colonum* and *Echinochloa crus-galli* and the dominant sedge was *Cyperus difformis* and the dominant broad-leaved weeds were *Ammania baccifera* and *Marselia* *quadrifolia* found in the experimental field in both the seasons. Weed density and weed dry weight recorded at 45 DAT revealed that significantly lesser mean weed density of 66/m^2 and weed dry weight of 80.77 g/m^2 recorded with PE application of premixed pretilachlor 6% + bensulfuron methyl 0.6% GR 10 kg /ha on 3 DAT + PoE application of herbicide bispyribac-sodium 10% SC 200 mL/ha on 20 DAT, which was comparable with PE application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl0.15% GR10 kg /ha on 3 DAT/ 7 DAS + PoE application of bispyribac sodium 10% SC 200 mL/ha on 20 DAT/ DAS (67.03/m^2 an+d 81.46 g/m^2). Considerable reduction in germination of *Echinochloa colonum* under sequential application of pretilachlor 6% + bensulfuron-methyl 0.6% GR 10 kg/ha and bispyribac-sodium 10% SC 200 mL/ha was the reason behind lesser weed density and dry weight also It might be due to the new pre-emergence herbicides under sulfonylurea group which would have suppress the density of weed flora at the early stages of crop itself and sequential application pre-emergence followed by post-emergence herbicide control broad spectrum of weeds in rice crop especially grasses which had grown along with rice crop seedlings in same hill and closer similarity of rice as documented by Jayadeva *et al.* (2019).

Higher mean weed control efficiency of 82.98% was registered in PE application of pre-mixed pretilachlor 6% + bensulfuron-methyl 0.6% GR 10 kg/ha on 3 DAT + PoE application of herbicide bispyribac-sodium 10% SC 200 mL /ha on 20 DAT and it was on par with PE application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl 0.15% GR10 kg/ha on 3 DAT/ 7 DAS + PoE application of bispyribac-sodium 10% SC 200 mL/ha on 20 DAT/ DAS (82.22%) than other herbicide combination. Pretilachlor is the commonly used pre-emergence herbicide for management of all weed species in rice. However, continuous adoption of rice based intensive cropping sequences with indiscriminate scheduling of fertilizer nutrient and irrigation regimes favour luxurious weed growth and enhanced the bulk accumulation of weeds seed reserve in soil profile which offer menace to the succeeding crops. Hence, the combined applications of different group of herbicides having ideal compatibility and synergetic effect as premixed or tank mixed applications. Moreover, the weeds that emerge at later periods are also to be contained with effective and economical post-emergence herbicidal applications. Through effective suppression of weeds with the above premixed pre-emergence herbicidal combination at early stages of crop growth and the post-emergence

Table 1. Influence of weed management practices on total weed density, dry matter production (DMP), weed control efficiency at 45 DAS, growth parameters of rice (pooled data of two seasons)

Treatment	Total weed density (no./m^2)	Weed dry weight (g/m^2)	WCE (%)
Unweeded control	(180.9)13.95	(1051.4)32.92	-
Two hand weeding (HW) on 20 and 40 DAT/ DAS	(78.3)9.35	(117.7)11.34	73.42
Premixed pretilachlor + bensulfuron-ethyl 10 kg/ha PE on 3 DAT / 7 DAS + HW on 40 DAT/DAS	(71.2)8.94	(100.0)10.49	78.50
Premixed pretilachlor + pyrazosulfuron-ethyl PE 10 kg/ha on 3 DAT/ 7 DAS + HW on 40 DAT/DAS	(86.0)9.77	(148.6)12.68	67.76
Premixed pretilachlor + bensulfuron-methyl PE 10 kg/ha on 3 DAT/ 7 DAS + PoE bispyribac-sodium 200 ml/ha on 20 DAT/DAS	(66.3)8.64	(80.8)9.48	82.98
Premixed pretilachlor + pyrazosulfuron-ethyl PE 10 kg/ha on 3 DAT /7 DAS + PoE bispyribac-sodium 200 ml/ha on 20 DAT/DAS	(67.0)8.68	(81.5)9.52	82.21
LSD (p=0.05)	1.9	1.2	-

Figures in parentheses are square root $\sqrt{(x + 0.5)}$ transformed values

Table 2. Influence of weed management practices on growth parameters, productive tillers, filled grain/panicle of rice (pooled data of two seasons)

Treatment	Plant height (cm)	DMP (t/ha)	Productive tillers	Filled grain/ panicle
Unweeded control	55.95	4645	238	108
Two hand weeding (HW) on 20 and 40 DAT/ DAS	65.77	5270	306	145
Premixed pretilachlor + bensulfuron-ethyl 10 kg/ha PE on 3 DAT / 7 DAS + HW on 40 DAT/DAS	70.86	5597	337	156
Premixed pretilachlor + pyrazosulfuron-ethyl PE 10 kg/ha on 3 DAT/ 7 DAS + HW on 40 DAT/DAS	60.82	4956	273	120
Premixed pretilachlor + bensulfuron-methyl PE 10 kg/ha on 3 DAT/ 7 DAS + PoE bispyribac-sodium 200 ml/ha on 20 DAT/DAS	78.11	6101	383	173
Premixed pretilachlor + pyrazosulfuron-ethyl PE 10 kg/ha on 3 DAT /7 DAS + PoE bispyribac-sodium 200 ml/ha on 20 DAT/DAS	76.13	5924	372	170
LSD (p=0.05)	2.3	0.09	2.2	

herbicidal applications in later stage might have effectively minimizes weed population, nutrient removal, dry matter production and in turn resulted in enhanced weed control efficiency. The results were in corroboration with the results documented by Palani *et al.* (2020). The lowest weed control efficiency was observed in hand weeding on 20 and 40 DAT because of hand weeding is a cultural approach to control weeds and also *Echinochloa colonum* young plant resemble rice, which makes hand weeding difficult early stage. This was the reason behind lesser weed control efficiency.

Effect on crop growth, yield attributes and yield

Growth and yield characters of rice has significantly influenced by weed management treatments. PE application of pre-mixed pretilachlor 6% + bensulfuron-methyl 0.6% GR 10 kg /ha on 3 DAT + PoE application of herbicide bispyribac-sodium 10% SC 200 mL/ha on 20 DAT produced significantly taller plants, highest DMP, productive tillers, filled grain/panicle than other herbicidal treatments. However, this was on par with PE application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl 0.15% GR 10 kg/ha on 3 DAT/ 7 DAS + PoE application of bispyribac-sodium 10% SC 200 mL /ha on 20 DAT/DAS. Planting a younger seedling with optimal growing conditions is responsible for accelerated growth rate in plants as these make possible to complete more phyllochrons before entering into their reproductive phase. Completion of more phyllochrons at early seedlings stage resulted in more number of tillers and effective tillers per hill and plant height of rice under different combination of herbicides showed comparable with each other. This is mainly because of reduced weed competition during early stages of crop growth with the simultaneous increase in the uptake of nutrients by the crop which favoured taller plants, increase assimilation surface which enhanced the crop growth characters and better control of weeds under this treatment would have favoured increased source sink relationship which resulted in more yield attributing characters (Ankit *et al.* 2018 and Yadav *et al.* 2017). Control plot produced significantly treatments, mainly due to higher weed competition.

Grain yield and straw of rice was significantly varied with weed management practices. PE application of pre-mixed pretilachlor 6% + bensulfuron-methyl 0.6% GR 10 kg/ha on 3 DAT + PoE application of herbicide bispyribac-sodium 10% SC 200 mL/ha on 20 DAT recorded significantly higher mean grain yield over other treatments and it was on par with PE application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl 0.15% GR 10 kg/ha on 3 DAT/ 7 DAS + PoE application of bispyribac-sodium 10% SC 200 mL/ha on 20 DAT/ DAS. This might be due to reduced weeds under sequential application of pre-emergence and post emergence herbicides applied plots resulted in competition free environment at the critical stages of crop favoured the crop to utilize the factors for crop growth and production and enhanced the well balanced source sink capacities and uniform stand of the crop due to application of pre and post emergence herbicides which attributed to the production of more DMP, productive tillers, filled grain/panicle compared to all other treatments and responsible for higher yield of rice. These were in accordance with the earlier findings of Teja *et al.* 2015.

Effect on economics

Economics of *Echinochloa colonum* weed management techniques in rice revealed that PE application of premixed pretilachlor 6% + bensulfuron-methyl 0.6% GR 10 kg/ha on 3 DAT + PoE application of herbicide bispyribac-sodium 10% SC 200 mL/ha on 20 DAT gave higher mean net returns and benefit cost ratio than other treatments and herbicide resulted in increased grain yield and reduced cost of weeding were reason behind higher net profit. Similar result has reported by Bhatt *et al.*

Table 3. Influence of weed management practices on grain yield, straw yield, return rupee invested (pooled data of two seasons)

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Net income ($x10^3$ Rs/ha)	Return/ rupee invested
	2022	2023	Pooled	2022	2023	Polled		
Unweeded control	2.76	2.14	2.45	4.68	3.44	4.06	8.95	1.32
Two hand weeding (HW) on 20 and 40 DAT/ DAS	5.33	3.85	4.59	8.64	6.59	7.62	34.16	2.0
Premixed pretilachlor + bensulfuron-ethyl 10 kg/ha PE on 3 DAT / 7 DAS + HW on 40 DAT/DAS	5.67	4.17	4.92	8.62	7.13	7.88	39.25	2.17
Premixed pretilachlor + pyrazosulfuron-ethyl PE 10 kg/ha on 3 DAT/ 7 DAS + HW on 40 DAT/DAS	4.88	3.40	4.14	7.86	5.79	6.83	29.00	1.89
Premixed pretilachlor + bensulfuron-methyl PE 10 kg/ha on 3 DAT/ 7 DAS + PoE bispyribac-sodium 200 ml/ha on 20 DAT/DAS	6.58	4.77	5.67	9.80	7.72	8.76	50.47	2.52
Premixed pretilachlor + pyrazosulfuron-ethyl PE 10 kg/ha on 3 DAT /7 DAS + PoE bispyribac-sodium 200 ml/ha on 20 DAT/DAS	6.33	4.58	5.46	9.95	7.61	8.78	48.14	2.47
LSD (p=0.05)			39					

(2017). Hand weeding on 20 and 40 DAS gave lesser net return mainly due to higher cost of manual weeding. Control plot recorded negative net returns in both the seasons due to higher weed competition led to lesser grain yield.

Thus, it can be concluded that PE application of pre-mixed pretilachlor 6% + bensulfuron-methyl 0.6% GR 10 kg/ha on 3 DAT + PoE application of herbicide bispyribac-sodium 10% SC 200 mL /ha on 20 DAT followed by PE application of pre-mixed pretilachlor 6% + pyrazosulfuron-ethyl0.15% GR 10 kg/ha on 3 DAT/ 7 DAS + PoE application of bispyribac- sodium 10% SC 200 mL/ha on 20 DAT/ DAS controlled the jungle rice *(Echinochloa colona)* effectively and produced higher profitability of rice in transplanted condition.

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RESEARCH ARTICLE

Weed seed bank and dynamics in wheat as affected by sowing time and rice residue management methods

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ABSTRACT

Field studies were carried out to evaluate the effect of sowing time and residue management methods of preceding rice varieties (with different residue load) on weed seed bank and density in wheat during *Rabi* 2019-20 and 2020-21 in Punjab. Experiment was conducted in split plot design keeping combinations of 2 preceding rice varieties with different residue loads and 2 sowing times in main plots and 4 residue management methods in sub-plots with 3 replications. Results revealed that weed population and biomass at 30 days after sowing was higher in fields with low residue load (6.96-7.89 t/ha of PR 126) as compared to high residue load (10.25-11.44 t/ha of PR 122). Population and biomass of *Medicago denticulata* was lower in 15th November sown wheat in contrast to other broad-leaf weeds. Lower density of *Phalaris minor* was recorded under early sown wheat (25th October). Weed density and biomass was lower under happy seeder as compared to other residue management methods. In mould board plough + rotavator treatment, weed seed per unit area was lower in 0-5 cm soil layer but it was higher at 10-15 cm soil depth as compared to other residue management methods. Crop growth parameters (plant height, tillers density and biomass) were not influenced by rice residue load and wheat planting time. Grain yield was recorded highest under early sown wheat as compared to late sown wheat. Grain yield was recorded highest under Happy Seeder as compared to other residue management system during second year. However, grain yield was recorded similar under all residue management methods during first year. The results suggested that grass weeds were less in 25th October sown wheat but 15th November sown crop has less broad-leaf weeds.

Keywords: Early sown wheat, Happy Seeder, Mould board plough, Residue burning, Residue removal, Rice varieties

INTRODUCTION

Rice-wheat is the dominant cropping system of Punjab and plays an important role in satisfying growing food demand. In Punjab, rice and wheat are grown on an area of 31.45 and 35.26 lakh hectares during 2021 and 2022 with production of 203.71 and 148.65 lakh tonnes and average yield of 64.78 and 42.16 quintals per hectare, respectively (Anonymous 2023). Though, this monoculture of rice-wheat has contributed a lot in making the state self-sufficient in food grains and improving the economic condition but continuous cultivation of rice has resulted into many problems such as rice residue burning, receding water table (Hira *et al.* 2004), less time period between two crops, yield plateau (Ladha *et al.* 2003), formation of sub-soil hard pan with a consequent increase in bulk density, multi-nutrient deficiencies, weed infestation and evolution of herbicide resistance (Singh *et al.* 2016) that are threatening the sustainability of rice-wheat cropping system.

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The combine harvesting of rice leaves stubbles of about 30-40 cm in height and spreads most of the straw in the field (Prasad *et al.* 1999). Burning of residue results in emission of harmful gases and poses a health hazard besides depleting soil health. Various solutions have been proposed to utilize crop residues such as incorporation, retention, baling and use in different industries. Beside this, long duration varieties of rice vacate the fields very late and cause delay in sowing of wheat beside leaving large residue load. The shift from conventional tillage to conservational tillage in wheat resulted in weed flora shift. In wheat, emergence of *Phalaris minor* was lower under zero tillage than conventional tillage (Chhokar *et al.* 2009) but some of the broad-leaf weeds, such as *Rumex dentatus* emerged in higher number in former (Chhokar *et al.* 2007). Further, more than 60% of weed seeds were concentrated in 0-7.5 cm soil layer in conventional/zero tillage (Hasam *et al.* 2021). Crop residue and tillage practices not only influence weed growth and population but also influence the efficacy of pre-emergence herbicides (Kaur *et al.* 2021). In Punjab, *P. minor* has evolved resistance against isoproturon (Malik and Singh 1995), clodinafop and sulfosulfuron

(Chokkar and Malik 2002). The combined adoption of multiple weed control options, both chemical and non-chemical practices such as change in tillage practices, residue management (retention or incorporation) will help in effective management of weeds in wheat. It was hypothesized that weed density and biomass will be affected by rice residue load and wheat planting time under different residue management methods. An experiment was conducted to study weed seed bank dynamics as affected by different residue loads, sowing time and residue management methods.

MATERIALS AND METHODS

Two years field study was conducted during 2019-20 and 2020-21 at student's research farm of Agronomy, Punjab Agricultural University, Ludhiana (Punjab). The maximum temperature in February-March was higher by 1ºC during 2020-21 than 2019-20. The soil of experimental site was sandy loam texture with 0.35% organic carbon and pH of 7.79. Available N, P and K content in the soil were 210, 32.75, 183.50 kg/ha, respectively. The experiment was conducted in spilt plot design with three replications. The main-plot consisted of 4 combinations of 2 preceding rice varieties and 2 wheat sowing time. The variety '*PR 122*' (with residue load of 10.25 and 11.44 t/ha during 2019-20 and 2020-21, respectively) and '*PR 126*' (with residue load 7.89 and 6.96 t/ha during 2019-20 and 2020-21, respectively) were cultivated in the previous summer season (June-October months). In winter season (October to April), wheat was sown at two different times *i.e.* 25th October and 15th November. In sub-plots, four methods of rice residue management, *viz.* conventional (residue removal followed by conventional tillage), Happy Seeder, mould board plough followed by rotavator and burning were allocated for the study. The harvesting of previous rice crop was done by using combine fitted with super straw management system. Under conventional method, rice straw was removed manually and controlled burning was done in burning plots. In Happy Seeder sowing method, wheat was sown in standing stubbles having loose straw without any seedbed preparation. Seed-cum-fertilizer drill was used for wheat sowing in prepared seed-bed. Wheat variety '*Unnat*' *PBW 343* (with seed rate of 100 kg/ha) was sown in rows at 22.5 cm row spacing. The application of nitrogen, phosphorus and potassium was done at the rate of 125 kg/ha N, 60 kg/ha P and 30 kg/ha K using urea, diammonium phosphate and murate of potash, respectively. Whole quantity of P and K was applied as basal dose at sowing while N was top dressed in two equal splits at 4 and 6 weeks after sowing. In conventional method, urea was applied after irrigation application while it was applied a day before irrigation in Happy Seeder.

A quadrate of 50 × 50 cm was placed at two places in each plot to determine the density and biomass of different weeds after 30 days of sowing (DAS). Weed dry weight was recorded after drying the weed samples at 70°C for 48 hr. Weed seed bank study was done by adopting germination method described by Espeland *et al.* (2010). Soil samples were taken from each sub-plot with the help of auger core sampler from 0-5, 5-10 and 10-15 cm soil depth one day before and after rice residue management. To separate weed seeds from the soil, the soil samples were washed with a 0.2 mm sieve cloth. Seed samples were transferred to Petri plates lined with wet filter papers in laboratory. Weed seed germination was recorded at a weekly interval, until no germination occurred in the dishes. Germination tests were performed at 25-30°C temperatures and sufficient conditions of moisture were maintained in the plates. The data was converted into viable m^2 seeds. Plant height (cm), tiller density (no./m^2) and crop dry matter accumulation (g/m^2) were measured at 90 days after sowing of the crop. The grain yield was recorded from net plot at harvest. Data were analyzed as per analysis of variance technique for determining the statistical significance effect of applied treatments. For observations on weeds, the data of weed population and biomass were square root transformed before analysis. However, for better understanding, original values are given in parenthesis. While the ANOVA indicated significant treatment effects, means were separated at $p<0.05$ and adjusted with Fisher's protected least significant difference (LSD) test.

RESULTS AND DISCUSSION

Weed seed bank

Seed bank of *M. denticulata, R. dentatus,* and *P. minor* were observed at 0-5 cm, 5-10 cm and 10-15 cm depth of soil before residue management (**Figure 1**). Weed seed bank was not significantly influenced by different rice residue load and wheat planting time during both the years. The numbers of seeds per unit area decreases with increase in soil depth. Seed bank of *M. denticulata, R. dentatus* and *P. minor* was more at 0-5 cm soil depth as compared to 5-10 cm and 10-15 cm soil profile. Similar results were reported by Chokkar *et al.* (2009).

After residue management, three broad-leaf weeds namely *M. denticulata, A. arvensis, R. dentatus,* and one grass *P. minor* were observed in the weed seed bank study at 0-5 cm, 5-10 cm and 10-15 cm depth of soil after residue management (**Figure 2**). The seeds of different weeds were lower under mould board plough + rotavator at 0-5 cm (surface soil layer) as compared to other systems. However, at 10-15 cm soil depth, mould board plough + rotavator results in significantly higher weed seeds as compared to other residue management system during both the crop seasons. This could be due to inversion of soil by mould board plough, results in dormant seed at surface. This might be due to burial of viable seed at lower soil depth. Intensive tillage brought the weed seeds to the shallow depth thus exposing them to fluctuating temperature and sunlight, which enhanced the emergence of weed seeds. At 5-10 cm soil depth, seed bank of different weeds was statistically at par during both the crop seasons. Under no-till (Happy Seeder) conditions, much of weed seeds were located near the soil surface and number of weed seeds were declined with increase in depth (Yenish *et al.* 1992).

Weed density at 30 DAS

Weed flora of the experimental field consisted mainly of broad-leaf weeds *Medicago denticulata, Anagallis arvensis, Rumex dentatus, Coronopus didymus* and *Melilotus indica.* Among grasses, only *Phalaris minor* was observed. Weed density of all broad-leaf weeds and grass weed were significantly influenced by rice residue load during 2019-20 (**Table 1**). Higher weed population per unit area was recorded under lesser residue load (*PR 126*) as compared to higher residue load of '*PR 122*' in the first year. This might be due to fact that high residue load acts as a physical barrier for weeds, which hinders their emergence. Similarly, less weed emergence under higher residue load was reported by Kumar *et al.* (2013). A lower number of weeds was observed under high residue load of *PR 122* during 2020-21; however, the differences between weed densities under two residue loads were non-significant.

Planting time of wheat had significant effect on density of *M. denticulata* during both the years (**Table 1**). It was observed that significantly higher number of plants of *M. denticulata* per unit area was recorded under early sown wheat (25th October) as compared to late sown (15th November) wheat during both the years. In contrast, other broad-leaf weeds like *R. dentatus, A. arvensis, C. didymus, M. indica* and grass weed *P. minor* were recorded significantly lower when wheat was sown on 25th October during both the years. *Medicago denticulata* can germinate over temperature range of 10-20°C (Kumar *et al.* 2013) and temperature during end-October were favourable for growth and germination of *M. denticulata*. However, other weeds may require lower temperature for their germination and growth as compared to *M. denticulata*. This might be due to the fact that *P. minor* germinates at cooler temperature which was achieved on 15th November. Similarly, Singh *et al.* (2019) observed that *P. minor* density was maximum in wheat sown on 15th November.

Table 1. Effect of different rice residue load, wheat planting time and rice residue management methods on weed density (no./m^2) at 30 DAS

Treatment	*M. denticulata*		*M. indica*		*R. dentatus*		*A. arvensis*		*C. didymus*		*P. minor*	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Preceding crop variety												
PR122	11.10 (126)	13.32 (184)	2.62 (9)	3.52 (15)	4.28 (22)	4.97 (26)	5.66 (46)	8.35 (83)	2.24 (6)	2.53 (6)	3.21 (14)	8.52 (75)
PR126	12.42 (164)	14.83 (227)	3.07 (12)	3.19 (11)	6.15 (40)	4.20 (18)	7.46 (57)	10.40 (87)	3.36 (11)	2.92 (8)	3.99 (15)	9.00 (83)
LSD (p=0.05)	0.67	NS	0.15	NS	0.58	NS	0.74	NS	0.42	NS	0.43	NS
Date of sowing of wheat												
25-Oct	13.84 (196)	16.23 (266)	1.50 (2)	2.04 (4)	3.83 (16)	4.10 (17)	5.01 (35)	8.19 (70)	1.73 (3)	2.32 (5)	2.36 (7)	7.69 (59)
15-Nov	9.68 (94)	11.92 (146)	4.19 (19)	4.67 (22)	6.60 (45)	5.08 (28)	8.12 (68)	10.56 (112)	3.87 (15)	3.13 (9)	4.83 (23)	9.83 (99)
LSD (p=0.05)	0.67	1.59	0.15	0.37	0.58	0.58	0.74	0.49	0.42	0.45	0.43	0.51
Rice residue management system												
Residue removal	12.64 (164)	14.04 (204)	3.36 (14)	3.43 (14)	5.58 (33)	5.20 (27)	6.98 (58)	9.77 (97)	2.96 (10)	2.99 (8)	3.86 (17)	9.09 (83)
Happy seeder	9.71 (96)	12.69 (168)	1.65 (3)	2.63 (8)	3.98 (19)	2.86 (8)	5.37 (36)	8.28 (72)	2.35 (6)	2.16 (4)	3.14 (11)	7.41 (55)
MB plough + Rotavator	11.53 (140)	13.97 (200)	2.40 (6)	3.00 (10)	4.87 (26)	4.54 (21)	6.15 (45)	8.83 (81)	2.58 (7)	2.66 (7)	3.45 (13)	8.50 (72)
Residue burning	13.15 (181)	15.61 (251)	3.98 (18)	4.34 (20)	6.44 (44)	5.74 (33)	7.74 (67)	10.61 (114)	3.32 (12)	3.08 (9)	3.94 (18)	10.05 (106)
LSD (p=0.05)	0.96	1.48	0.23	0.54	0.74	0.53	0.69	0.52	0.31	0.42	0.38	0.89

Interactions between treatments in main, main×sub plots were found non-significant during 2019-20 while interaction between treatments in main plots was found significant during 2020-21. Weed data is subjected to square root transformation ($\sqrt{x+1}$). and means of original values are given in parentheses

Residue management practices significantly influenced the density of broad-leaf weeds as well as grass weed during both the years. During 2019-20, significantly lower weed population was observed under Happy Seeder as compared to other management methods such as mould board plough+ rotavator, conventional tillage and burning (**Table 1**). This might be due to mulching effect of straw on soil surface under Happy Seeder plots as compared to other plots in which there is no residue on surface. Residue at the surface hinders the weed germination by creating physical barrier for emergence of seedling of broad leaf weeds and by reducing the light penetration for grass weeds. These results were in front line with Chhokar *et al.* (2021). However, during 2020-21, significantly lower density of different weeds was recorded under Happy Seeder as compared to conventional tillage and burning, but it was found statistically similar with mould board plough+ rotavator. *Phalaris minor* density was lowered in Happy Seeder sown wheat (Saini and Walia 2010). Further, residue incorporation by mould board plough+ rotavator resulted in significantly lower weed population than burning during both the years. These results are supported by findings of Khankhane *et al.* (2009).

The interaction between date of sowing and rice residue load on weed density was significant and differential during second year. On 25th October sown wheat, there was significant effect of rice residue load on population of *M. denticulata* and *P. minor* (**Table 2**) and population was lower under high residue load of '*PR 122*' but in late sown (15th November) wheat, effect of residue load on weed emergence was not visible. This could be due to the rainfall received in early-November which resulted in faster decomposition of residue. The density of *A. arvensis* was affected by residue load and it was less under high residue load under both sowing time of wheat.

Weed biomass at 30 DAS

Rice residue load significantly influenced biomass of broad-leaf weeds in first year however, the differences were non-significant during second year (**Table 3**). The biomass of broad leaf weeds was significantly lower when wheat was sown on 15th November as compared to 25th October. This might be due to fact that the major weed at experimental site was *M. denticulata* and higher weed density of *M. denticulata* was recorded at 25th October which results in higher biomass. In contrast, biomass of *P. minor* was lower when wheat was sown on 25th October as compared to 15th November. This could be due to more density of *P. minor* when wheat is sown on 15th November. Similar results were reported by Mahajan and Brar (2002) that wheat sown in November has more problem of *P. minor* because of decline in temperature.

Different rice residue management practices significantly affected the weed biomass during both years. During 2019-20, lower biomass of weeds was observed under Happy Seeder as compared to mould board plough+ rotavator, conventional tillage and burning. However, Happy Seeder was found statistically at par with mould board plough + rotavator but significantly better than conventional tillage and burning, during 2020-21. This could be due to lower weed population per unit area under Happy Seeder as compared to conventional tillage and burning. Also, retention of rice residue reduced biomass of weeds by suppressing weed population due to physical barrier and also by allelochemical released from rice residue mulch, which inhibit weed seed germination.

Table 3. Effect of different rice residue load, wheat planting time and rice residue management methods on weed biomass (g/m^2) at 30 DAS during 2019-20 and 2020-21

Treatment	Broad-leaf weeds		Grass weeds	
	2019-20	2020-21	2019-20	2020-21
Preceding crop variety				
PR122	3.88 (15)	6.32 (40)	2.01 (4)	3.19 (13)
PR126	4.32 (19)	6.47 (42)	2.31 (4)	4.01 (15)
LSD (p=0.05)	0.22	NS	0.2	0.25
Date of sowing of wheat				
25-Oct	4.79 (23)	7.45 (55)	1.59 (2)	3.07 (12)
15-Nov	3.41 (11)	5.34 (29)	2.73 (7)	4.18 (15)
LSD (p=0.05)	0.22	0.63	0.2	0.25
Rice residue management				
Residue removal	4.36 (19)	6.47 (43)	2.29 (5)	4.12 (17)
Happy Seeder	3.46 (10)	5.67 (33)	1.93 (3)	2.27 (5)
MB plough+ rotavator	3.75 (13)	6.27 (40)	2.09 (4)	4.10 (17)
Residue burning	4.56 (21)	7.17 (52)	2.34 (5)	4.25 (18)
LSD (p=0.05)	0.32	0.63	0.18	0.23

Interactions between main, main×sub plots are found non-significant during 2019-20

Weed data is subjected to square root transformation ($\sqrt{x+1}$). and means of original values are given in parentheses

Table 2. Interactive effect of rice residue load and date of sowing on weed density (no./m^2) at 30 DAS during 2020-21

Sowing time	*PR122*	*PR126*	*PR122*	*PR126*	*PR122*	*PR126*
	M. denticulata		*A. arvensis*		*P. minor*	
25-Oct	15.47 (241)	16.57 (275)	6.80 (47)	9.60 (92)	7.40 (54)	9.00 (84)
15-Nov	11.48 (128)	12.36 (164)	9.90 (98)	11.20 (126)	9.90 (101)	9.71 (97)
LSD (p=0.05)	0.88		0.69		0.71	

Weed data is subjected to square root transformation ($\sqrt{x+1}$) and means of original values are given in parentheses

Table 4. Effect of different rice residue load, wheat planting time, rice residue management and weed management methods on growth parameters and grain yield of wheat

Treatment	Plant height (cm) at 90 DAS		Tiller density (no./m^2) at 90 DAS		Crop biomass (g/m^2) at 90 DAS		Grain yield (t/ha)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Preceding crop variety								
PR122	83.25	76.65	482.31	477.78	588.47	563.56	5.06	4.68
PR126	82.41	73.76	470.56	472.32	572.35	552.85	4.87	4.64
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Date of sowing of wheat								
25-Oct	83.26	76.59	496.9	480.78	580.71	563.88	5.12	5.00
15-Nov	82.41	73.82	455.96	469.32	580.11	552.53	4.80	4.32
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	0.23	0.27
Rice residue management								
Residue removal	82.97	75.26	465.44	465.79	580.67	558.42	4.95	4.52
Happy Seeder	83.44	75.78	498	501.54	581.06	558.33	5.09	5.00
MB plough + rotavator	82.88	75.64	492.95	486.52	580.81	558.72	4.93	4.63
Residue burning	82.13	74.14	449.33	446.36	579.11	557.33	4.89	4.48
LSD (p=0.05)	NS	NS	40.27	31.33	NS	NS	NS	0.20

Crop growth parameters and yield

Plant height and crop biomass were not affected by rice residue load, wheat planting time and rice residue management system during both crop seasons (**Table 4**). Different loads of rice residue and wheat planting time did not influence the tiller density of wheat during both years. The rice residue management methods recorded significantly higher tiller density as compared to conventional method, and the lowest being under burning. The data were in agreement with the findings of Singh *et al.* (2011) who also observed higher tiller mortality of wheat under no mulch conditions. Rice residue load did not significantly affect the grain yield during both years. Wheat planting time significantly affected the grain yield of wheat during both years. The grain yield was 7.35 and 15.63 % higher when wheat was sown on 25th October as compared to 15th November sown wheat during 2019-20 and 2020-21, respectively. This could be due to better crop growth during early sowing of wheat. The poor germination and growth of weeds favoured crop growth and resulted in higher grain yield under early sown conditions. These results are in front line with Singh *et al.* (2019).

The methods of rice straw management did not significantly affect the grain yield of wheat, during 2019-20. Similarly, Bhattacharyya *et al.* (2008) found the non-significant change in grain yield of wheat under zero tillage as compared to conventional method. The temperature was higher during grain filling and maturity time during 2020-21. Plots with residue retention (Happy Seeder) lead to significantly higher grain yield as compared to conventional method. Residue retention as mulch helps in protecting crop from terminal heat stress. Wheat grain yield was 7.87, 10.56 and 12.14 % higher in Happy Seeder plot as compared to mould board plough *fb* rotavator, residue removal and burning, respectively. Crop residue management is one of the vital issues for sustainability in north-western Indian states, and its *in-situ* management (residue retention or incorporation) may result in improving soil fertility along with effective weed control and sustainable productivity of rice-wheat cropping system.

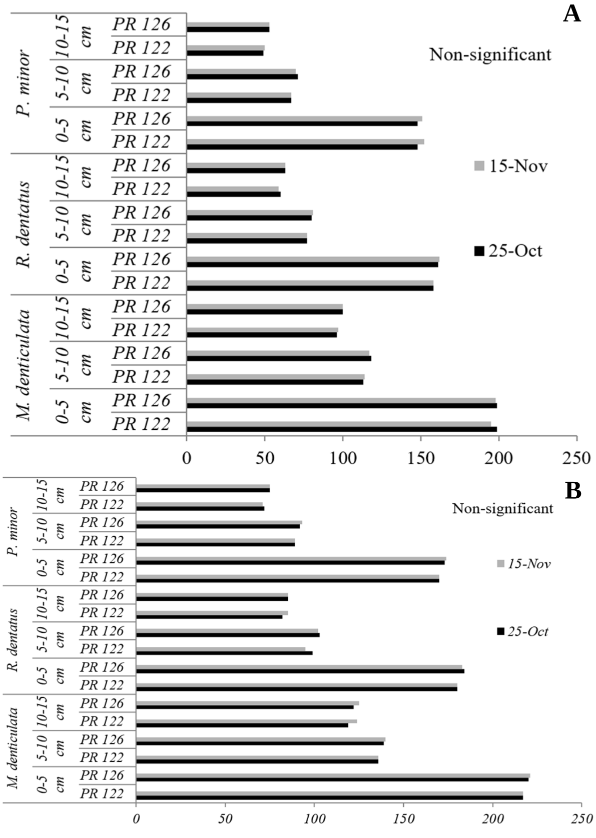

Figure 1. Weed seed bank no./m^2 before residue management methods as affected by preceding rice varieties and sowing time; a and b graph indicate weed seed bank before residue management during 2019-20 and 2020-21, respectively; NS: Treatment means are non-significant at p<0.05.

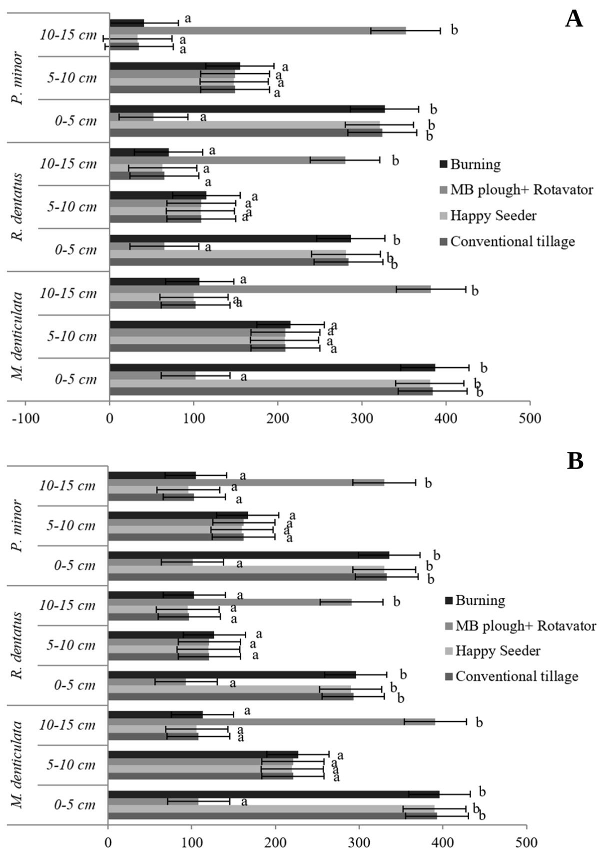

Figure 2. Weed seed bank no./m² as affected by residue management methods; a and b graph indicate weed seed bank after management during 2019-20 and 2020-21, respectively; Mean values not connected by the same letter are significantly different according to p<0.05. Vertical error bars depict standard error of mean.

It was concluded that weed population and biomass was more in plots with lesser residue load of '*PR 126*' as compared to '*PR 122*'. Residue incorporation with mould board plough resulted in a smaller number of weed seed bank in the 0-5 cm soil layer. *Medicago denticulata* density was more in 25th October sown wheat than in 15th November sown wheat however, *Phalaris minor* density was less in early sowing of wheat sown on 25th October.

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RESEARCH ARTICLE

Synergistic effects of herbicide safener on tembotrione behavior in irrigated Inceptisols, weed obstruction and maize productivity

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ABSTRACT

Lab and field experiments were conducted to investigate the synergistic effects of safener isoxadifen-ethyl on tembotrione (TBT) persistence, sorption and leaching behavior in maize cultivated Inceptisol. Batch sorption indicated that the most stable time of its sorption in Inceptisol is 12 h irrespective of safener addition. Tembotrione showed moderate affinity to soil solids with Kfoc values of 17.08 - 26.29. Tembotrione dissipation followed first-order kinetics with a mean half-life of 15 days and was influenced by application rate, safener, soil pH and organic carbon content. Terminal residue in maize grain was below minimum residue limit set by European Food Safety Standard (0.02 mg/kg), though detected (0.012 mg/kg) above detection limit in soil applied with double recommended rate of TBT. The weed control efficiency was 62.37 and 61.35 percent respectively in recommended and double recommended rate and produced higher grain yield too. Study authenticated that the TBT 120 g/ha with safener, isoxadifen-ethyl 1000 mL/ha is safe to soil environment and provide effective weed control in maize under tropical Inceptisols.

Keywords: Dissipation, HPLC Isoxadifen-ethyl, Maize, Safener, Sorption, Synergistic effects, Tembotrione

INTRODUCTION

Tembotrione [2-{2-chloro-4-mesyl-3-[(2,2,2 trifluoroethoxy) methyl] benzoyl} cyclohexane -1,3-dione] is a new generation low dose herbicide belongs to synthetic triketone family. It is a selective post-emergence herbicide applied to control grasses and broad-leaved weeds in maize (Santel 2009). This contact herbicide acts by disrupting carotenoid biosynthesis through inhibition of 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme (Schulte and Kocher 2009). Its application to maize field is recommended along with safener isoxadifen-ethyl as it enhances tolerance of cereal crops to herbicides by effectively inducing cellular xenobiotic detoxification mechanisms besides improving the selectivity (Sun *et al.* 2017, Gonsiorkiewicz Rigo *et al.* 2021). Though the safeners enhance the crop safety, they might also show phytotoxicity to crops when its concentration is high. Combined application of herbicide foramsulfuron with isoxadifen has increased its translocation to corn parts and its adsorption in soil (Bunting *et al.* 2004). Hence it is essential to know the synergistic influence of safener, isoxadifen-ethyl on the persistence and sorption of TBT in tropical Inceptisols of semi-arid region.

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Tembotrione is stable to hydrolysis at environmental pH range of 5–9 but prone to photolysis in soil and water (USEPA 2007). Its degradation in soil strongly depends on pH and highest degradation rate was observed in more alkaline soils (AGES 2012, Rani *et al.* 2020). The loss of cyclohexane dione moiety from the benzene ring and to non-toxic phenol compounds under feasible environment is degradation pathway of tembotrione (TBT) in soil environment (Dumas *et al.* 2017 and Rani *et al.* 2020). In aerobic soils, it degrades biologically with a half-life ranged from 4 to 56 days (Macbean 2008, USEPA 2007). In acid soil, it undergoes photo degradation following biphasic pattern with rapid initial dissipation to 60% by 3 days and subsequent distinct slow dissipation with photolysis half-life of 0.7 days (AGES, 2012). Tembotrione and its metabolite also showed first order dissipation kinetics in clay loam and sandy loam soils with half-life from 7.2 to 13.4 days under controlled conditions (Rani *et al.* 2020). Being a weak acidic compound with a pKa value 3.17–2.98 and solubility 71 g/L at 20^{o}C in water, it can exist in different tautomeric forms which largely depend upon the environmental conditions and soil pH (Dumas *et al.* 2017). Since it is not adsorbed to the suspended solids and soil sediments and released into water due to the estimated Kfoc of 14, it has high mobility in soil and the potential to leach into ground water (USEPA 2007). Maximum TBT retention in 15–25 cm soil depth with limited leaching was also observed in clay loam soil than the sandy loam soil (Rani *et al.* 2020) though its metabolite showed appreciable leaching potential in sandy loam soil. It is generally established that sorption checks the pesticide degradation by reducing their partition into the soil liquid phase (Farmer and Aochi 1987).

Herbicide safeners, are chemical agents applied along with herbicides to increase the tolerance of crops to herbicides without affecting the weed control effectiveness mainly through providing selectivity and counteraction of the residual action of soil applied herbicides (Jablonkai 2013). Mostly the safeners were developed to increase tolerance of monocotyledon cereal plants and applied along with pre-emergence herbicides. Trends toward post-emergence herbicide treatments and the use of high-activity herbicide molecules have led to the development of safeners with post-emergence application in winter cereals which were subsequently evaluated and recommended for application in wheat, rice and maize (Rosinger *et al.* 2012 and Jablonkai 2013).

In India, tembotrione (TBT) has been registered for use in maize as pre- and early post-emergence herbicide. Mostly the published literatures revealed only the bio efficacy of tembotrione in tropical condition and its dissipation behavior in acidic soils. No published or only limited information on its dynamic behavior in high pH soil of semi-arid tropical condition. Therefore, field and laboratory experiments were undertaken to investigate the behavior of TBT in irrigated Inceptisol and its terminal residues in maize, weed obstruction and its productivity when applied with safener, isoxadifen-ethyl.

MATERIALS AND METHODS

Weather and climate

The normal weather of the experimental location was documented every day. Maximum temperature in the cropping period ranged from 29.9°C to 36.4°C with a mean of 32.5°C. The minimum temperature ranged from 19.6°C to 24.4°C with a mean of 21.71°C. A total rainfall of 283.10 mm was received during the cropping period. The mean sunshine hours during the cropping period were 6.1 h and the mean morning and evening relative humidity were 85.5 and 48.7 percent, respectively.

Field experiment details

Field experiment was conducted at TNAU Eastern block farm, Coimbatore which has a semi - arid and tropical climate with dry summer and cool winter. The experimental farm is positioned at 11°0’27’’ N Latitude, 76°56’29’’ E Longitude at an altitude of 426.7 m above mean sea level in the Western Zone of Tamil Nadu. The experiment was laid out in randomized block design with five treatments replicated four times. The size of each plot was 4 ×5 m. Maize (*Zea Mays* L.) hybrid ‘*CO 6*’ of TNAU was sown during winter (*Rabi*) 2016-17. The test chemical Laudis 42% SC (34.4% W/W), manufactured by the M/S. Bayer’s Crop Science Ltd., was applied as early post-emergence (2-3 leaves stages of weeds) at two rates, *viz*. 120 and 240 g/ha with and without herbicide safener isoxadifen-ethyl (0.25 % V/V) at 1000 and 2000 mL/ha as an early post-mergence spray in maize field on 15th day after sowing (DAS) with the help of a knapsack sprayer. Safener isoxadifen-ethyl was applied as per the treatment along with the TBT herbicide. Control treatment without herbicide was maintained as weed free for comparison. The soil samples were collected at 0 (2 h), 1, 3, 5, 10, 30, 45 and 60 day time intervals after its application and at maize harvest (120 days after herbicide application) from all the treated and untreated (control) plots. The soil of the experimental field was mixed black calcareous, moderately deep and well-drained, sandy clay loam in texture and classified as Inceptisol (*Typic Ustropept*). It has alkaline pH 8.45 and EC 0.32 dS/m and low in available N and high in available P and K status and 0.54% organic carbon.

Soil samples were drawn randomly from 0-15 cm depth using a tube auger from five selected spots in each plot and pooled to have approximately 500 g. Soil sample of each plot was homogenized by blending conscientiously and spread on a clean plastic sheet for size reduction. It was portioned into four equal quarters and opposite two quarters was discarded by retaining the other two quarters. Quartering and removing process was repeated to reach 100 g representative sample for final analysis. Collected soil samples were air-dried, powdered and passed through a 2 mm sieve before analysis. Maize cobs were harvested from net plot, processed and yield was expressed in kg/ha 14% moisture content. Three whole plant samples constituting about 500 g was randomly collected from each plot during harvest, cut into small pieces, homogenized for representative sub sampling. Similarly, the maize cobs were collected from each plot, thrashed and processed for analysis. About 50 g grain and stover from each treatment was sub sampled and powdered for residue analysis.

Laboratory experiment details

The batch adsorption experiment was conducted to determine the equilibrium time for assessing the TBT sorption (mg/L) with and without safener (2 ml/L) in soil at an interval of 6, 12 and 18 h. Both the herbicide formulation and safener were mixed well and used for the study. Bulk soil samples collected from the experimental field before the start of experiment was processed and used for the lab study. For adsorption studies, five grams of soil samples were placed in required number of centrifuge tubes and to which different concentrations of herbicides active ingredients (0, 0.1, 0.2, 0.5, 1.0, 2.0, 5.0 and 10.0 mg/L) prepared in 0.01M $CaCl_2$ were added with 1:5 soil: solution ratioand the experiment was duplicated for each time interval. The soil solution suspension in centrifuge tubes was shaken in an end over end shaker at ambient temperature to attain equilibrium. At each interval, two sets of each treatment were removed and centrifuged at 5000 rpm for 10 minutes maintained at 20^{o}C and the supernatant was filtered through Paul nylon membrane filters of < 2 ìm. Filtrate was extracted for tembotrione residue and determined in HPLC-DAD. The amount adsorbed (mg/kg) was calculated using the formulae

$$Cs = (Ci-Ce)*v/m$$

where Cs = the amount of solute adsorbed from the solution. v = Volume of the adsorbate, Ci = the concentration added (mg/L), Ce = the concentration in equilibrium solution (mg/L) and m = the weight in gram of the adsorbent.

Tembotrione extraction and clean up

A valid homogenized representative laboratory sub sample of soil was taken in centrifuge tube and vortexed with known volume of acetonitrile: 0.1 % acetic acid (50/50 v/v) as reported by Rani *et al* (2020). The mixture was shaken in orbital shaker for 1 hr at 60 rpm and then centrifuged at 2500 rpm for 5 minutes. Supernatant was filtered, transferred to separating funnel and partitioned using known volume of petroleum ether twice. Petroleum-ethyl layer was collected and pooled for clean-up. Powdered and homogenized maize grain and straw were extracted using distilled water by shaking an hour and centrifuging at 5000 rpm for 5 minutes. Supernatant was filtered and partitioned using hexane and ethyl acetate (2:3 v/v ratio) and 5% NaCl. Organic layer was collected and re-partitioned with di-chloromethane twice. Pooled dichloromethane layer was subjected to clean up. Extracted TBT residue was cleaned up using Na_2SO_4 and dried in rotary vacuum evaporator to moist condition. Residue was re-dissolved in 2 ml acetonitrile for HPLC analysis. Tembotrione residue from adsorption studies was extracted following the method as described for soil samples.

HPLC conditions for tembotrione determination

The tembotrione residue was determined by Agilent HPLC (1200 series) equipped with Diode Array Detector (DAD), binary pump and auto sampler with rheodyne injection system. The separation of compound was performed using Agilent Eclipse XDB-C 18, 5 µm, 4.6 × 150 mm column kept in thermo stated oven maintained at 30^{o}C. The instrument connected to a computer records the response in terms of peak area using the Ezchrome software. The mobile phase consists of 80:20% (v/v) acetonitrile and 0.02% ortho phosphoric acid at flow rate of 0.5 mL min^{-1} was used in binary mode to separate the TBT. The absorption was measured at 285 nm by injecting 10 µl sample.

Method validation

Stock solution of TBT (100 mg/L) was prepared in acetonitrile using certified reference material. The working standards of TBT were prepared by serial dilution from the stock solution. Then, 0.5 µL of each working standards were injected into HPLC and the peak area was measured for linearity check study. Validation of method was executed in terms of recovery studies before analyzing unknown samples as reported by Janaki *et al.* (2013).

Data analysis

For linear sorption isotherms, the TBT sorption coefficient, K_d [L/kg] was calculated by $K_d=C_s/C_e$ (Janaki *et al.* 2013) where C_s is the amount of herbicide sorbed by the soil [mg/kg] and C_e is the herbicide concentration of the soil solution at equilibrium [mg/L]. The value of K_d was determined from the slope of the linear plots of sorbed Vs aqueous TBT concentrations. The amount of TBT sorption per unit soil organic carbon (SOC), K_{oc}, or per unit of clay, K_c, was determined using the formula K_{oc} or K_c = (K_d/SOC or clay %) × 100.

Tembotrione degradation was described using the first order kinetics equation as described by Janaki *et al.* (2013). The half-life of the herbicide molecule was determined using the equation $T_{1/2}$= 0.6931/k. Where 'k' is the degradation constant.

RESULTS AND DISCUSSION

Under the optimized HPLC conditions, the tembotrione was detected at 8.42 $\pm$ 0.2 minutes as sharp peak. The limit of detection (LOD) and limit of quantification (LOQ) by HPLC was, 0.01 and 0.05 mg/kg, respectively. Similar LOQ for maize straw was reported by Su *et al*. (2020). Analytical calibration curve was linear (r^2=0.9970**) in the range of 0.01 to 1.00 mg/L. Tembotrione recovery from spiked soil and maize parts with three concentrations from 0.01 to 0.5 mg/kg was more than 80 per cent confirmed the suitability of the extraction protocol for TBT from different matrices.

Tembotrione behavior in soil under laboratory conditions

Results divulged the influence of safener on time required to reach TBT sorption equilibrium. Soil solution reached equilibrium by 6 and 12 hr (**Figure 1**), respectively in TBT alone and TBT with safener added treatments. In case of TBT alone treatment, much change was not observed on 12 and 18 hr compared to 6 hr. Similarly, the TBT with safener applied treatment did not show much change on 18 h when compared to 12 hr. This time-dependent adsorption can be a result of physical and chemical nonequilibrium and has been attributed to several factors, such as diffusive mass transfer resistances, rate-limited adsorption reactions etc. (Jensen and Escudey 2019). In the present study, the variation in

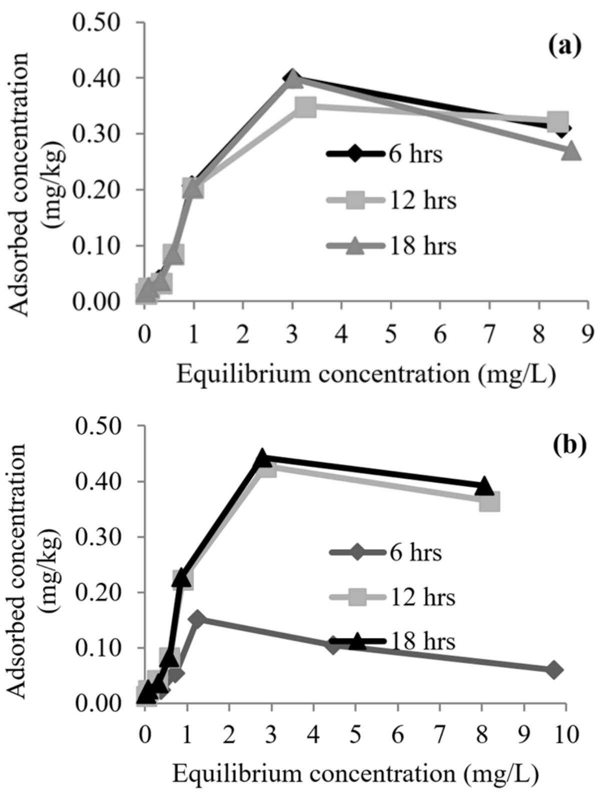

Figure 1. Tembotrione adsorption in maize soil revealed by batch equilibrium experiment (a. tembotrione alone; b. tembotrione +isoxadifenethy)

Table 1. Tembotrione adsorption isotherms parameters by simple linear model

Treatment	Isotherm parameters			
	K_d(L/g)	R^2	K_{oc}	K_c
6 h				
Tembotrione	0.177	0.714	16.22	0.263
Tembotrione + isoxadifen-ethyl	0.025	0.253	5.110	0.080
12 h				
Tembotrione	0.170	0.796	15.33	0.249
Tembotrione + isoxadifen-ethyl	0.091	0.754	18.48	0.300
18 h				
Tembotrione	0.170	0.648	15.32	0.249
Tembotrione + isoxadifen-ethyl	0.096	0.770	19.49	0.320

time and adsorption rate could be ascribed to the slow release of TBT to soil solution freely due to the modification of TBT sorption behavior by the safener isoxadifen-ethyl. It was confirmed by the significant correlation between TBT sorbed and equilibrium concentrations (**Table 1**).

Sorption data at 6 hr and 12 hr fitted to the linear function showed good correlation between equilibrium and sorbed concentration in TBT alone applied soil whereas 12 and 18 hr interval showed significant correlation in tembotrine with safener applied soil. This again confirmed that the inclusion of safener isoxadifen-ethyl increased the time required to reach the equilibrium solution concentration (**Table 3**). The results were also confirmed by the distribution coefficient (Kd), r^2 and Koc (15.32 – 16.22) values which was high in the TBT alone received soil. Similar Koc value of 12 was reported by USEPA (2007). Estimated low Koc value suggests that TBT is expected to have very high mobility in soil due to the low adsorption capacity. Its low interaction with soil properties like organic carbon, carbonates, metal oxides, clay and its type etc., could be attributed to its chemical nature particularly negative charge (Gabriela Zemeka 2015) of its tautomeric form in the experimental soil pH of 8.54.

The Freundlich empirical constant (Kf) representing the soil sorption capacity (**Figure 2**) for a given range of herbicide concentration was higher at 6 hr (0.914) and 12 hr (1.288) for TBT alone and TBT with isoxadifen-ethyl treatments, respectively (**Table 2**). The Freundlich parameter (n) values, was inferior to 1 in both the treatments and showed 'L' type sorption. This signified a moderate affinity between soil solids and TBT and a decreased availability of adsorption sites with increased liquid

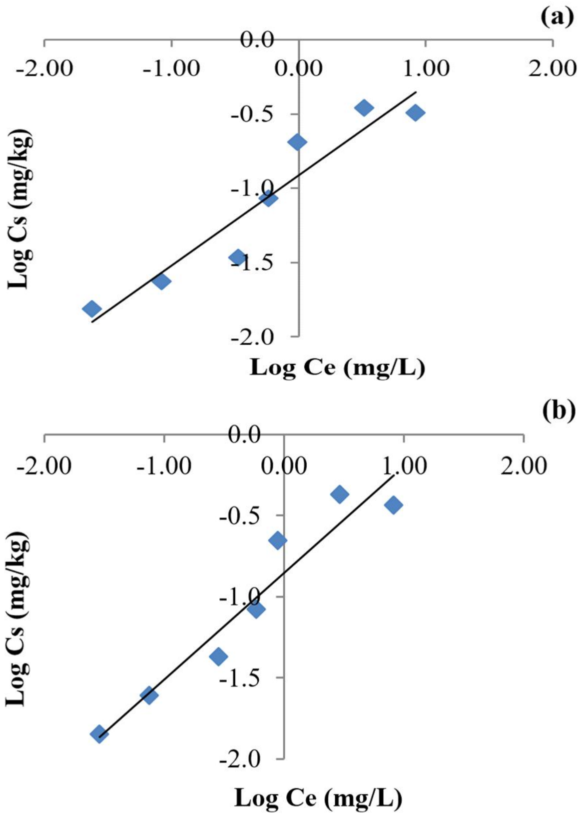

Figure 2. Linear plots of freundlich isotherm for tembotrione adsorption in maize soil after 12 h of equilibrium (a. tembotrione alone; b. tembotrione +isoxadifenethy)

Treatment	Isotherm parameters			
	K_f (L/g)	n	R^2	K_{foc}
6 h				
Tembotrione	0.892	0.611	0.909	18.20
Tembotrione + isoxadifen-ethyl	1.288	0.369	0.648	26.29
12 h				
Tembotrione	0.914	0.608	0.908	18.65
Tembotrione + isoxadifen-ethyl	0.852	0.656	0.925	17.39
18 h				
Tembotrione	0.809	0.037	0.003	16.51
Tembotrione + isoxadifen-ethyl	0.837	0.598	0.883	17.08

concentration (Faria *et al.* 2019). The R^2 of TBT sorption in both the treatments were >0.95 at 12 hr and provedthat the most stable time of TBT sorption in Inceptisol is 12 h irrespective of safener addition. Gabriela Zemeka (2015) reported 6 hr as stable time for TBT adsorption in Vertisol. The calculated Kfoc values were ranged from 17.08 to 26.29 with higher values in TBT with isoxadifen-ethyl treatment.

Being weak acid, only the part in the molecular form could be adsorbed and hence easily repelled by the negative groups on the surface of soil (Faria*et al.* 2019). The presence of organic matter and metal ions in high pH soils might also affects the herbicides sorption as the precipitation of metal ions reduces it interaction with herbicides. If not precipitates, the metal cations raise the herbicides sorption with residual negative charges as a result of electrostatic attraction (Rani *et al.* 2020). Thus, the present sorption study reveals that the TBT has moderate sorption behavior in Inceptisols and is modified by the soil pH besides the clay and organic matter content.

Tembotrione dissipation in soil and terminal residue in maize

Initial TBT deposit detected on day 0 (2 hr after TBT application) ranged from 0.0404, 0.1245, 0.0521 and 0.1745 mg/kg soil at 120, 240 g/ha without and with safener, respectively. Tembotrione 240 g/ha + 2000 ml safener recorded higher residue compared to 120 g/ha with or without safener. Residue detected in soil increased from 0 to 5 days and then decreased and ranged from 0.0801-0.2641 mg/kg on 5th day. It persisted in soil up to 45 and 60 days after application corresponds to lower and higher rates irrespective of safener addition (**Figure 3**) and then the residues became below the quantification limit. Similar results were reported by Dyson *et al.* (2002) for the mesotrione which persist in soil up to 32 days and were depending on the environmental conditions and type of soil. Stability of TBT to hydrolysis at environmental pH range of 5–9 (USEPA, 2007), might be responsible for its persistence in soil up to 60 days. Results also showed that the application of TBT with safener enhanced its persistence in soil and could be ascribed to the increased addition of TBT residue to soil through decomposing weeds which might have absorbed and retained more residue due to selectivity of safener. Wichert *et al.* (1999) also reported that the foliar uptake of triketone by weed species is rapid and 40 to 70% of the mesotrione chemical being absorbed within an hour of application.

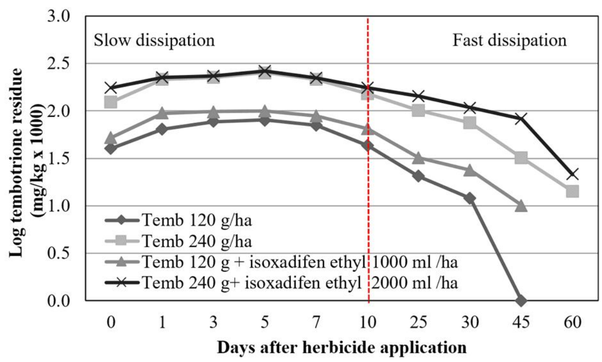

Figure 3. Degradation of tembotrione in maize cultivated Inceptisol (Temb – Tembotrione)

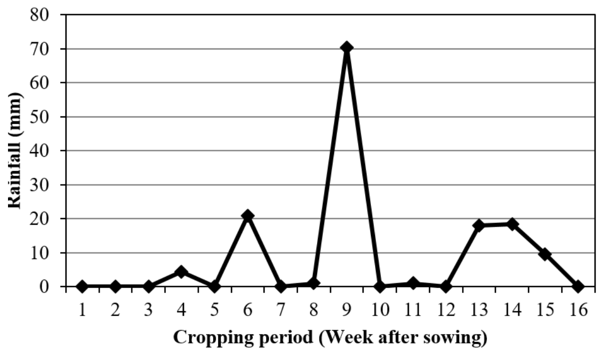

Figure 4. Rainfall received during the maize cultivation period

Dissipation of TBT was arrived using the highest residue detected on 5th day (**Table 3**). More than 50 per cent of the residue has dissipated from soil on 25th day in all the plots except at higher rate with safener and 50% dissipation occurs on 30th day in the plot that received 240 g/ha and safener 2000 mL/ha. This could be ascribed to the enhanced degradation and leaching of TBT by the high rainfall occurred during 6th and 9th weeks after its spray corresponds to 21 and 70.5 mm, respectively (**Figure 4**). Residue was not detected on day 90 of application. Tembotrione dissipated slowly from soil when it was applied with safener, and 36 and 34% was noted respectively in 120 and 240 g/ha plots on day 10 after application. At the above two rates, 85 and 71% dissipation were observed without safener plots and 76 and 59% with safener plots on day 30. Kucharski and Sadowski (2009) found addition of adjuvants reduced the degradation rate of phenmedipham in soil. More than 90% of the applied TBT dissipated from soil on day 60 in double the rate applied plot and on 45th day from the recommended rate plot irrespective of safener addition. Similar longer persistence of TBT residues in double dose was observed by Rani *et al*. (2020) during later stages of its degradation in clay loam and sandy loam soils.

Tembotrione dissipation profile best followed the first-order and 1.5th order reaction kinetics (**Table 3** and **4**). The coefficient of determination (R^2) between log residues and time varied from 0.9773**-0.9920** (significant at P = 0.01), 0.9685** - 0.8891* (significant at P = 0.05) and 0.9328** - 0.7905* (significant at P = 0.05), for 1st, 1.5th and 2nd orders, respectively. This indicated that the TBT dissipation could be well accounted by first-order kinetics followed by 1.5th order. Similar first order kinetics of TBT was also observed in clay loam and sandy loam soils by Rani *et al.* (2020). Mean half-life of TBT ranged from 9.1 to 20.5 days and increased with increased rate and safener addition in the present experiment. Half-life of 6 to 14 days and 10 to 22 days respectively in soil exposed to sunlight and or dark was reported in literature (EFSA, 2013 and Barchanska *et al.* 2016) for TBT degradation. Higher half-life in safener applied plot could be ascribed to the reduced leaching of TBT through soil profile.

Table 3. Persistence of tembotrione in maize cultivated Inceptisol

Time (DAA)	Residue concentration (mg/kg) ±SD[a]			
	Tembotrione 120 g/ha	Tembotrione 240 g/ha	Tembotrione 120 g/ha + 1000 ml isoxadifen-ethyl	Tembotrione 240 g/ha+ 2000 ml isoxadifen-ethyl
0	0.0404± 0.009	0.1245± 0.008	0.0521± 0.011	0.1745± 0.009
1	0.0642± 0.008	0.2148± 0.007	0.0945± 0.010	0.2248± 0.010
3	0.0768± 0.011	0.2245± 0.009	0.0987± 0.009	0.2343± 0.009
5	0.0801± 0.008	0.2541± 0.011	0.1002± 0.008	0.2641± 0.011
7	0.0708 ± 0.007 (11.6)	0.2145± 0.010 (15.6)	0.0886± 0.007 (11.6)	0.2219± 0.009 (16.0)
10	0.0432 ± 0.009 (46.1)	0.1513± 0.008 (40.5)	0.0646± 0.008 (35.5)	0.1745± 0.008 (33.9)
25	0.0204± 0.011 (74.5)	0.1004± 0.009 (60.5)	0.0318± 0.007 (68.2)	0.1425± 0.009 (46.4)
30	0.012± 0.006 (85.0)	0.0745± 0.007 (70.6)	0.0237± 0.006 (76.4)	0.1084± 0.007 (59.0)
45	BDL	0.032± 0.007 (87.4)	0.0101± 0.006 (90.0)	0.0825± 0.008 (68.8)
60	BDL	0.0142± 0.011 (94.4)	BDL	0.02141± 0.011 (91.9)
90	BDL	BDL	BDL	BDL

[a]Average of three replicates; SD: standard deviation; figures in parentheses designate % dissipation; BDL- below detectable level, DAA: Days after application

Table 4. Half-life, correlation coefficient and regression equation tembotrione degradation in maize cultivated Inceptisol

Tembotrione treatment	Half-life (days)	Regression equation	Correlation coefficient r^2
Tembotrione 120 g/ha	9.75	Y=2.2071+0.0763	0.9748
Tembotrione 240 g/ha	14.44	Y=1.2132+0.048	0.9773
Tembotrione 120 g/ha + 1000 ml isoxadifen-ethyl	12.12	Y=2.0273+0.0572	0.9920
Tembotrione 240 g/ha + 2000 ml isoxadifen-ethyl	20.51	Y=1.2225+0.0338	0.9485

Kucharski and Sadowski (2009) found that the DT_{50} value for phenmedipham + oil adjuvant mixture was about 11 days higher in comparison with phenmedipham alone. In the present experimental Inceptisol, the TBT degraded moderately with a mean half-life of 14 days which could have been strongly influenced by the higher soil pH (AGES 2012, Rani *et al.* 2020). Alkaline pH of soil could have accelerated the chemical degradation of TBT by detaching the cyclohexane dione moiety from benzene ring and further to non-toxic phenol compounds (Dumas *et al.* 2017 and Rani *et al.* 2020). Medium organic carbon (OC) content (5.4 g/kg soil) of the present experimental alkaline Inceptisol might have also hastened the TBT degradation. This could be attributed to the electrostatic interaction between anionic TBT with positive charge present with minerals and organic matter in soil at alkaline pH particularly the divalent calcium ions dominating in the present experimental soil. Rani *et al.* (2020) stated that TBTdegradation rate is highly influenced by organic matter content and pH of the soil and observed a slightly higher dissipation in clay loam soil with 0.48% OC than sandy loam soil with 0.38% OC.

Terminal residues of TBT in soil and maize plant parts at harvest (120 DAS) was determined since the herbicides applied in soil are also taken in by the plants and metabolized or accumulated as such in different plant parts. In the present study, TBT terminal residues were seen below the detectable limit (0.01 mg/kg) in soil irrespective of rates and safener addition. However, the residue was detected above BDL (0.012 mg/kg) in the soil of plot that received TBT 240 g/ha and safener 2000 mL/ha. This showed that the increased rate of TBT and safener might have increased its persistence time by reducing its solubility and leaching from soil. Kucharski and Sadowski (2009) found that the addition of adjuvants caused an increase of the phenmedipham residues in soil and roots of sugar beet and reduced its degradation rate in soil. It is generally established that sorption checks the pesticide degradation by reducing their partition into the soil liquid phase (Farmer and Aochi 1987). Detectable residue (>0.01 ppm) was not found on day 120 of application in maize grain and stover at any of the rate which is well below the existing MRL (0.02 mg/kg) proposed by European Union for tembotrione residue in maize grain (EFSA 2018). This could be attributed to the capacity of maize plant to metabolize TBT into dihydroxy tembotrione and subsequently benzoic acid which is the dominant metabolite found in maize at maturity (EFSA, 2018).

Weed obstruction, phytotoxicity to maize and yield

Significant variation in total weed density and dry weight was observed among the TBT applied plots at 40 days after sowing (**Table 5** and **Figure 5**). Tembotrione applied with safener controls the weeds appreciably than without safener plots. This showed that the safener isoxadifen-ethyl helps in the selectivity of weeds and crop to TBT and hence provided efficient weed control. Though increased dose of TBT decreased the weed density (5.17 no./m^2) and dry weight (4.91 g/m^2), TBT applied at 120 g/ha with isoxadifen 1000 mL/ha also gave effective weed control efficiency of 62.37 per cent without phytotoxicity to maize plant. Singh *et al.* (2012) noticed that tank mix of TBT 120 g/ha as PoE along with safener recorded significantly lower weed density and higher weed control efficiency. Weed control efficiency was found to range from 30.43 to 50.05% in the TBT applied plots but without safener isoxadifen-ethyl.

Maize tolerance to applied TBT with and without safener isoxadifen-ethyl was observed on 1, 3, 7 and 15 days and evaluated using phytotoxicity scorings. Tembotrione applied at higher rate of 240 g/ha with or

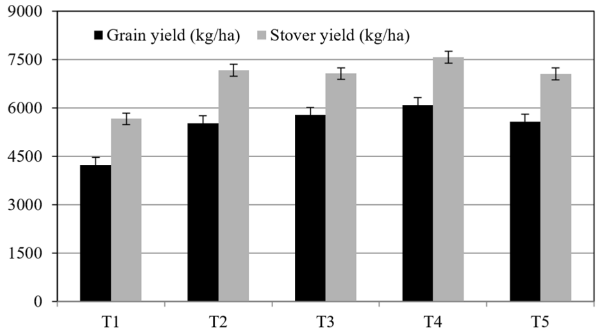

Figure 5. Synergistic effect of safener isoxadifen-ethyl and tembotrione on maize yield in Inceptisol (T1-Control; T2-Tembotrione 120 g/ha; T3-Tembotrione 240 g/ha; T4-Tembotrione 120 g/ha + 1000 ml safener; T4-Tembotrione 240 g/ha + 2000 ml safener; Error bar indicates standard error deviation)

Treatment	Total weed* density (no/m^2)	Total weed dry* weight (g/m^2)	Weed control efficiency (%)
Control	8.23 (65.80)	8.88 (76.92)	-
Tembotrione 120 g/ha	6.90 (45.78)	6.53 (40.76)	30.43
Tembotrione 240 g/ha	5.90 (32.87)	6.22 (36.70)	50.05
Tembotrione 120 g/ha + 1000 ml isoxadifen-ethyl	5.23 (25.42)	5.34 (26.54)	62.37
Tembotrione 240 g/ha + 2000 ml isoxadifen-ethyl	5.17 (24.76)	4.91 (22.10)	61.35
SED	0.24	0.27	-
LSD (p=0.05)	0.48	0.55	-

*Data subjected to SQRT ($\sqrt{x+2}$) transformation – Figures in parentheses are original values without safener showed chlorosis and necrosis to maize on 3rd day. Symptom was visualized even after 7 days with a rating one in TBT applied plot (240 g/ha) without safener. Affected plants recovered completely after 10 days in all plots and the phytotoxicity was not evident thereafter. However, the maize is tolerant to TBT when applied at recommended rate of 120 g/ha. Present results are in line with the findings of Ankush Kumar *et al.* (2017) who have not observed TBT phytotoxicity on maize when applied at recommended rate. On 7th day, symptoms were not seen in the plot applied with TBT 240 g/ha with safener. This could be ascribed to the enhanced metabolism of TBT in maize induced by the isoxadifen-ethyl as it is a safener (Santel 2009, Schulte and Kocher 2009).

Maize grain yield was increased by the TBT irrespective of rate and isoxadifen-ethyl addition. Grain and stover yield increased from 31-44 and 25-34 % respectively due to TBT and safner addition compared to weed control (hand weeded) plot. Tembotrione applied with isoxadifen-ethyl at recommended rate 120 g/ha produced significantly higher maize grain and stover yield when compared to 240 g/ha with or without safener (**Figure 5**). This could be attributed to the increased weed control through the improved weed and crop selectivity by TBT persuade by the co-application of safener isoxadifen-ethyl. Significantly higher grain yield in maize by the TBT application 120 g/ha as PoE along with safener was also reported by Singh *et al.* (2012). Higher maize grain yield of 3.77 t/ha in the TBT 120 g/ha + safener 1000 mL/ha plot compared to without safener (3.61 t/ha) was observed by Ankush Kumar *et al.* (2017). Decreased of grain and stover yield (9 and 8 percent respectively) in the plot received higher TBT (240 g/ha) with isoxadifen-ethyl (2000 mL/ha) could be ascribed to the increased phytotoxicity. This was confirmed by the negative and significant correlation of crop phytotoxicity rating on 3rd day with maize stover biomass (r^2= -0.732**). Similarly, Ankush Kumar *et al.* (2017) reported higher maize grain yield of 3.77 t/ha in the TBT 120 g/ha + safener 1000 mL/ha plot compared to no safener (3.61 t/ha).

The study revealed that the TBT sorption in sandy clay loam Inceptisol with alkaline pH followed 'L' type sorption with stable sorption time of 12 hr and dissipated following first-order kinetics with a mean half-life 14.79 days. Its dissipation was found to be rate dependent and safener inclusion and was highly influenced by the soil pH and organic carbon content. Tembotrione terminal residue was detected above BDL (0.012 mg/kg) in soil received 240 g/ha with safener 2000 mL/ha. The recommended rate of TBT applied with safener controls the weed appreciably and produced higher grain yield without phyto-toxicity. The study authenticated that the TBT at 240 g/ha with safener isoxadifen-ethyl 1000 mL/ha is relatively safe to soil environment and producing effective weed control in Indian tropical Inceptisols.

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RESEARCH ARTICLE

Effect of integrated weed management on summer greengram under alluvial soil of West Bengal

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ABSTRACT

Uncontrolled weeds cause severe yield loss in summer greengram. These weeds can be managed by physical, mechanical, chemical and through integrated approach. The present study was formulated to evaluate the effect of integrated weed management on summer greengram during 2017 and 2018 in alluvial soil of West Bengal. Altogether five treatments were fitted in randomized block design replicated four times. Treatments comprising of weedy check, twice hand weeding at 20 and 40 days after sowing, mechanical weeding (MW) at 20 and 40 DAS, imazethapyr 75 g/ha at 15 DAS *fb* MW at 40 DAS and aqueous extract of cucumber (*Cucumis sativus* L.) 10% 2.5 L/ha as PE *fb* MW at 40 DAS. Results revealed that, at early stage of crop growth, pre-emergence application of cucumber aqueous extract 10% recorded the weed control efficiency of 70.55% at 10 DAS and sustained 61.48% and 57.02% up to 25 DAS and 50 DAS, respectively. Hand weeding twice recorded the highest WCE of 81.98% at 25 DAS and 66.54% at 50 DAS followed by application of imazethapyr 75 g/ha at 25 DAS (73.50) and 50 DAS (62.08%), respectively. Different weed management options increased the greengram yield by 24.05% to 73.42% over weedy check. Two hand weeding recorded the highest seed yield of 1.37 t/ha, which gave 75.64% yield advantage over weedy check. Highest net return and maximum B: C ratio was registered in the application of imazethapyr 75 g/ha followed by a mechanical weeding. The composition and dosages of chemical and botanical herbicides have been proven to have a considerable impact on soil microorganisms with the inhibitory effect being noticeable shortly after its application which subsides later. This indicates that integrated weed management practices were more effective to reduce weed seed bank and possible options for cost-effective weed management in greengram.

Keywords: Allelopathy, Greengram, Integrated weed management, Seed yield, Weed management

INTRODUCTION

Greengram [*Vigna radiata* (L.) Wilczek] is an important pulse crop grown worldwide for grains. It is cultivated either as sole or inter crop especially with jute in West Bengal. Greengram is invaluable in crop rotation as it helped in improving soil fertility and provides sustainability to agricultural production system. As it has potential of utilizing limited soil moisture and nutrients, farmers grow this crop under adverse conditions also. Generally, in West Bengal, greengram is cultivated during summer season. It is called poor man's meat due to its high having protein content (25%). Though it is an important crop, several factors are responsible for poor quality and low yield of greengram. Among those, weed infestation is one of the major factors. Gharde *et al.* (2018) reported around 11 billion USD monetary loss due to weeds from 10 major crops of India. Whereas, uncontrolled weed causes up to 53% yield loss in summer greengram under West Bengal conditions (Tamang *et al.* 2015). The extent of losses depends on the weed types, intensity of infestation and critical crop-weed competition. Most of the greengram varieties are of short duration (~60–65 days); weeds create severe competition unless controlled timely and effectively within 15 to 30 days after sowing. In the Eastern India, generally, hand weeding, inter-row tillage are practiced for managing weeds in greengram. Adhikary (2016) noted that hand weeding is eco-friendly but time consuming and labor intensive. There is growing shortage of workers weeding greengram. In some states, wages for weeding operation are even higher than for regular farm work. Farmers very often fail to remove weeds due to unavailability of skilled labor as when required. This has compelled the farmers to resort to herbicides in greengram for weed control. Less labor-intensive herbicidal management allows effective weed control over large area within a short of span time. Singh *et al.* (2015) reported that as early post-emergence application, imazethapyr can manage weeds of

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greengram. And being an imidazolinone group herbicide, it is found superior against all types of weeds in pulses (Kumar and Hiremath 2018). Apart from chemical herbicides, in more developed agricultural systems, plant allelopathy is being exploited to control weeds. Different plants contain different types of allelochemicals that have the ability to suppress weed seed germination and growth. Such an allelochemicals bearing plant is cucumber (*Cucumis sativus* L.). Aqueous extract of different plant parts (leaf, stem, roots *etc*) of cucumber inhibited the growth of cress, alfalfa, ryegrass, timothy, crabgrass, *Echinichloa crus-galli* and *Echinichloa colonum* (Noguchi *et al.* 2015). Ahikary *et al.* (2014) registered 55.8% weed control efficiency in soybean when cucumber plant extract was applied as pre-emergence. Pre- or early post-emergence herbicides only control weeds for a short period and there after late-emerging weeds begin to compete with the crops. Single application of herbicide is ineffective in controlling later emerging weeds. Hence, in consideration of the above facts, the use of pre-emergence herbicides to manage early emerging weeds and mechanical weeding at later stage in sequence to manage late emerging weeds may be essential. The weeds can be managed by adopting several methods including eco–physical (physical and ecological), chemical and integrated weed management. Under the above perspectives, the present study was carried out to evaluate the effect of integrated weed management on growth, yield and economics of summer greengram in alluvial soils of West Bengal.

MATERIALS AND METHODS

A field experiment was conducted in the humid subtropics at the Instructional Farm of Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, Nadia, West Bengal during summer season of 2017 and 2018. The experimental site was situated at 22.93°N latitude and 88.53°E longitude with an altitude of 9.75 meters above mean sea level. The experiment was laid out in a randomized complete block design with five treatments and four replications. The treatments were weedy check, two hand weeding (HW) at 20 and 40 days after sowing (DAS), mechanical weeding (MW) at 20 and 40 DAS, imazethapyr 75 g/ha as early post-emergence (EPoE) at 15 DAS *fb* MW at 40 DAS and aqueous extract of cucumber (*Cucumis sativus* L.) 10% 2.5 L/ha as PE *fb* MW at 40 DAS. Aqueous extract was prepared as per the procedure described by Adhikary (2012). The inflorescence, leaves, stems and twigs of cucumber plant species were collected from the Instructional Farm (BCKV). The collected samples were dried in shade at room temperature for a week and later dried at 40 °C in oven for 48 hours and ground to prepare the dry powder. Aqueous extract was prepared by using 100 g of dry powder dissolved in 1000 ml of distilled water for 24 hours to obtain it in a concentration of 10%. Then it was filtered, and the filtrate was boiled at a temperature of 60 °C for two hours to concentrate the volume. The final extract was left to stand at 40°C for 30 minutes and then filtered. The aqueous extract was used for spraying in the specific plots on the next day after mixing with non-ionic surfactant (Tween 80). The chemical herbicides as well as cucumber (*Cucumis sativus* L.) aqueous extract were sprayed at spray volume of 500 liters/ha using knapsack sprayer fitted with flood jet deflector (WFN040 nozzle). Greengram (Cv. *WBM 4-34-1-1*) seeds treated with recommended *Rhizobium* strain (supplied by Nodule Research Laboratory, Bidhan Chandra Krishi Viswavidyalaya) were sown at a row-to-row distance of 30 cm and plant-to-plant distance of 10 cm. A recommended basal dose of 20 kg N, 40 kg P, and 40 kg K were applied at the time of sowing. The sources of N, P, and K were urea, single super phosphate, and muriate of potash, respectively. The weed flora was recorded to identify different weed species intercepted in the experimental field throughout the crop season. Data on weed density and biomass were recorded at 10, 25 and 50 DAS, and weed control efficiency (WCE) of different treatments was computed on the basis of weed biomass. Plant height, chlorophyll content, LAI and CGR were recorded at 25 and 50 DAS. Yield attributes were also recorded at harvest. To estimate the microbial population, fresh soil samples weighing 200 g were collected from each plot at the time of sowing (initial), at 7 and 14 DAA (days after application) and at harvest. The soil was collected from five locations in between the greengram rows. The enumeration of microbial population was done by using serial dilution technique and agar/pour plate method (Pramer and Schmidt 1964).

Enumeration of the colony-forming units (CFU) of fungi, total bacteria, and actinomycetes was done in Martin's Rose Bengal Fungal Streptomycin Agar Medioum, Thorton's Agar Medium, and Jensen's Agar Medium, respectively. The plates were incubated at 28 ± 1^0C for different durations between 5 – 7 days in BOD incubator and observations in terms of counting of number of colonies/plate were made (Adhikary *et al*. 2014). The costs of all inputs such as land preparation, greengram seed, planting, fertilizer, irrigation, harvesting, *etc*. were combined into a common cost of cultivation for all treatments. The costs of treatments included the costs of herbicides (as applicable). The minimum support price of greengram, declared by the Government of India, was used for calculating the gross returns. The net return was calculated by deducting the cost of cultivation from the gross return. The benefit: cost (B:C) was calculated from the gross return divided by the cost of production. Data on crops and weeds were analyzed using the analysis of variance (ANOVA) technique to evaluate the differences among treatments, and the means were separated using the least significant difference (LSD) at the 5% level of significance (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect of treatments on weeds

In the current study, the observed weed flora comprised of *Cynodon dactylon* (bermuda grass), *Dactyloctenium aegyptium* (Egyptian crowfoot grass), *Echinochloa colona* (barnyard grass), *Echinochloa crusgalli* (sawan grass), *Eleusine indica* (goose grass), *Setaria glauca* (foxtail grass), *Cyperus rotundus* (purple nut sedge), *Portulaca oleracea* (purslane), *Physalis minima* (native gooseberry), *Amaranthus viridis* (pig weed), *Euphorbia hirta* (asthma herb), *Commelina benghalensis* (Benghal dayflower), *Ageratum conyzoides* (billygoat weed), *Euphorbia hirta* (garden spurge), *Trianthema monogynya* (horse purselane) and *Alternanthera philoxeroides* (alligator weed). Similar findings on weed flora were also observed by Maji *et al.* (2020).

The highest weed density (5.31/m^2 and 6.58/m^2) and weed dry matter (28.30 g/m^2 and 45.46 g/m^2) were recorded in weedy check plots at 25 and 50 DAS, respectively (**Table 1**). Application of cucumber aqueous extract 10% PE at 1 DAS recorded significantly the lowest total weed density (3.42 /m^2), weed dry matter (4.30 g/m^2) and highest weed control efficiency (WCE) of 70.55% at 10 DAS. Allelopathy of cucumber plant was applied as a weed management tool. Two potent growth inhibitory substances present in cucumber (*Cucumis sativus* L.) plants namely HMO (9-hydroxy-4,7-megastigmadien-9-one) and THMO (6,9,10-trihydroxy-4,7-megastigmadien-3-one). HMO and THMO have the ability to inhibit the seed germination and growth of different grass species. Similar allelopathy effect of cucumber extract was observed by Noguchi *et al.* (2015). Among the weed management treatments, two hand weeding recorded highest WCE of 81.98% and 66.54% at 25 and 50 DAS due to significant reduction in weed density and dry matter. Early post-emergence (EPoE) application of imazethapyr 75 g/ha at 15 DAS *fb* MW at 40 DAS significantly reduced total population of weeds (3.52 and 5.16/m^2) at 25 and 50 DAS respectively. Imazethapyr 75 g/ha at 15 DAS resulted effective suppression of weed dry matter accumulation and higher WCE of 73.50% and 62.08% at 25 and 50 DAS, respectively. Most of the annual weeds were completely removed by hand weeding twice and created more favorable conditions for crop growth by controlling later emerged perennial weeds. Superiority of manual weeding regarding effective weed management and higher productivity was also reported by Shil and Adhikary (2014) and Adhikary *et al.* (2016). Early post-emergence application of imazethapyr showed efficacy in controlling weeds of greengram crop. It is absorbed by roots and foliage, translocates throughout the xylem and phloem, and accumulated in the growing regions (Plaza *et al.* 2006). Therefore, it controls both emerged and multiple flushes of shallow germinated weed plant, including root or rhizome. It kills the weed by inhibition of acetolactate synthase (ALS) which hinders cell division and reduces carbohydrate translocation in the susceptible weed plants. The affected plant completely decayed on herbicide application in 7-20 days. These finding are supported by the results of Gupta *et al.* (2017) and Adhikary (2018). While mechanical weeding (MW) at 40 DAS was responsible for controlling of broad-leaved weeds which caused complete destruction of these weeds at 3-4 leaf stage.

Table 1. Effect of treatment on total weed density (no./m^2), dry weight (g/m^2), weed control efficiency (%) in greengram (pooled data of two years)

Treatment	Total weed density (no./m^2)			Dry weight (g/m^2)			Weed control efficiency (%)		
	10 DAS	25 DAS	50 DAS	10 DAS	25 DAS	50 DAS	10 DAS	25 DAS	50 DAS
Weedy check	4.9(22.9)	5.3(27.2)	6.6(42.2)	14.60	28.30	45.46	0.00	0.00	0.00
Hand weeding at 20 and 40 DAS	4.8(21.7)	3.1(8.5)	4.7(21.0)	12.90	5.10	15.21	11.64	81.98	66.54
Mechanical weeding (MW) at 20 and 40 DAS	4.9(22.9)	4.1(15.7)	5.6(30.2)	13.20	12.40	20.54	9.59	56.18	54.82
Imazethapyr 75 g/ha + MW at 40 DAS	4.7(21.5)	3.5(11.5)	5.2(25.7)	12.70	7.50	17.24	13.01	73.50	62.08
Cucumber aqueous extract 10% 2.5 liter/ha + MW at 40 DAS	3.4(10.7)	4.0(15.1)	5.6(31.0)	4.30	10.90	19.54	70.55	61.48	57.02
LSD (p=0.05)	0.53	0.34	0.42	2.136	1.968	16.297	-	-	-

*Data subjected to square root transformation; values in parentheses are original

Effect of treatments on crop

The numbers of nodule were significantly influenced by weed control practices (**Table 2**). Hand weeding twice recorded 63.4 % higher nodules per plant as compared to weedy check, which was statistically equal with the application of imazethapyr 75 g/ha *fb* MW at 40 DAS. Whereas, the weedy check plots recorded the lowest numbers of nodules on greengram resulting in significant reduction in chlorophyll content and leaf area index. The chlorophyll content of greengram differed significantly by weed management practices during crop growth. At 25 DAS, 8% higher chlorophyll content over weedy check was recorded in the treatment which received two hand weeding at 20 and 40 DAS which was at par with EPoE application of imazethapyr 75 g/ha *fb* MW at 40 DAS. Again, from the data of 50 DAS, it was clear that the chlorophyll content was reduced at the later stage of crop growth. Two hand weeding maintained highest (43.33) chlorophyll content at 50 DAS also. However, irrespective of mode of application, imazethapyr 75 g/ha *fb* MW at 40 DAS recorded significantly higher LAI as compared to weedy check, with the magnitude of increment of 75.2% followed by pre-emergence application of cucumber aqueous extract 10% 2.5 liter/ha (67.8%) on 25 DAS. Severe crop-weed competition for available resources adversely affected the nodulation in weedy check in the current experiment. Zaidi *et al.* (2005) found a significant inhibition of the nitrogenase activity on Bradyrhizobium-greengram system after application of metribuzin.

Generally, nodule initiation in greengram begins around 9 DAS. It appears that the PE applied cucumber aqueous extract 10% 2.5 liter/ha might have hindered nodule functioning since the commencement of nodule initiation, with the crop not being able to recover from the preliminary setback even during the later stages. On the contrary, EPoE application of imazethapyr 75 g/ha on 15 DAS (approximately 6-7 days after nodule initiation) had lesser inhibitory effect on nodulation due to having improved tolerance towards herbicidal toxicity. Additionally, the crop growth rate (CGR at 25 to 50 DAS) of the EPoE applied imazethapyr 75 g/ha and PE applied cucumber aqueous extract 10% 2.5 liter/ha was also significantly higher than weedy check. In fact, imazethapyr 75 g/ha *fb* MW at 40 DAS recorded at par CGR (14.3 g/m^2/day) with twice hand weeding (15.6 g/m^2/day). Higher dry matter accumulation per plant was observed with these weed control treatments, when applied in the early stages of crop growth. Greengram grew abundantly and produced more leaves and reproductive parts, resulting in higher accumulation of dry matter per plant. Being unwanted, unsuitable and harmful plants, weeds are so predominantly C_4 plants (metabolizing essential carbon) and grow vigorously. Vigorous growth and excessive development compete with all crops for nutrients, space, space, air, carbon dioxide (CO_2), water (H_2O), light, soil moisture, soil oxygen, *etc*.

Effect of treatments on yield

An examination of data showed positive effect of integrated weed management practices on number of pods/plant, length of pod (cm), number of seeds/pod and test weight of greengram. Among the yield attributing traits (**Table 3**), two hand weeding recorded 44.6, 31.7 and 44.5 % higher pods/plant, seeds/pod and test weight as well as 53.7% lengthy pod respectively over weedy check followed by EPoE applied imazethapyr 75 g/ha *fb* MW at 40 DAS and PE applied cucumber aqueous extract 10% 2.5 liter/ha *fb* MW at 40 DAS. Two hand weeding produced the highest seed yield (1.4 t/ha) (**Table 4**). Different weed management options increased the greengram yield by 24.05% to 73.42% over weedy check. 60.7% more yield was registered in imazethapyr 75 g/ha *fb* MW at 40 DAS (1.3 t/ha), indicating that EPoE application was more effective mode of weed management in greengram after hand weeding. Twice hand weeding at 20 and 40 DAS recorded significantly higher biological yield (4.9 t/ha) which was at par with EPoE imazethapyr 75 g/ha *fb* MW at 40 DAS (4.7 t/ha) and PE application of cucumber aqueous extract 10% *fb* MW at 40 DAS

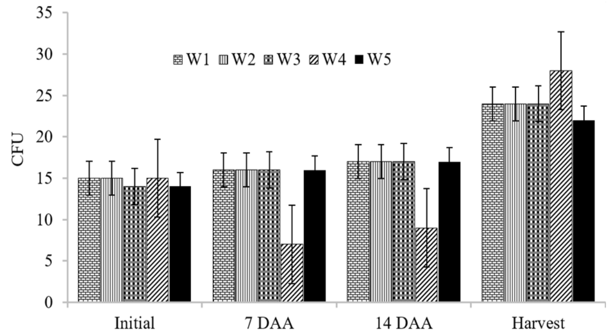
Table 2. Effect of treatment on nodule/plant, chlorophyll content (SPAD), leaf area index (LAI), and crop growth rate (CGR) (g/m^2/day) of greengram (pooled data of two years)

Treatment	Nodule /plant	Chlorophyll content (SPAD)		LAI		CGR (g/m^2/day)
		25 DAS	50 DAS	25 DAS	50 DAS	25–50 DAS
Weedy check	17.13	45.93	39.83	1.21	1.45	11.62
Hand weeding at 20 and 40 DAS	28.00	49.63	43.33	2.21	2.81	15.57
Mechanical weeding (MW) at 20 and 40 DAS	25.00	46.43	41.28	1.87	2.60	12.60
Imazethapyr 75 g/ha + MW at 40 DAS	26.88	49.62	43.08	2.12	2.73	14.34
Cucumber aqueous extract 10% 2.5 liter/ha + MW at 40 DAS	25.63	47.90	41.94	2.03	2.65	13.10
LSD (p=0.05)	2.01	1.03	0.83	0.15	0.09	1.27

(4.30 t/ha). However, the lowest biological yield (3.64 t/ha) was in weedy check plots. Though the treatment effect was non-significant, the crude protein content varied from 18.7% to 21.2% and harvest index (21.7% to 28.1%) across various treatments. Weed infestation has a detrimental effect on productivity and crop growth. Imazethapyr and cucumber aqueous extract treatment in greengram contributed to a significant increase in crop productivity that may have been attributed to improved crop competitiveness as evidenced by high WCE, CGR, and LAI, which might have minimized crop-weed competition for available resources and allowed the crop to utilize those resources more effectively. This tailored treatment's high yield resulted in higher B:C values, boosting profitability. According to the results of the correlation study, WCE on 25 DAS was significantly and positively correlated to CGR on 25–50 DAS, nodule/plant, yield components, and yield (**Table 5**), indicating that the elimination of weed interference within 25 DAS is essential for enhancing crop performance in general and yield maximization. The yield and crude protein content of the seeds were significantly impacted by LAI and test weight as well. This study highlights the critical role that weed control plays in the formation of the canopy and the legume-rhizobium symbiosis, which indirectly contribute to the ultimate yield of greengram.

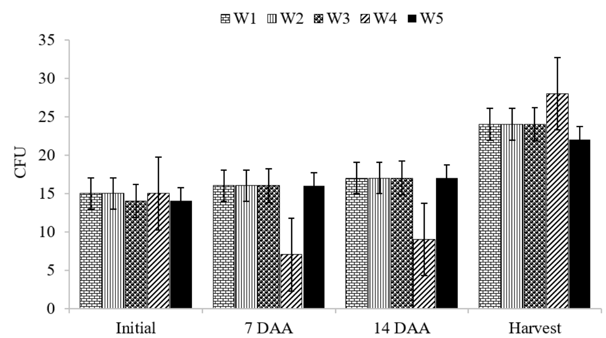
Effect of treatments on soil micro flora

The weed management options did not show any significant influence on the population of micro



W1-Weedy check; W2- Hand weeding at 20 and 40 DAS; W3- Mechanical weeding (MW) at 20 and 40 DAS; W4-Imazethapyr 75 g/ha + MW at 40 DAS; W5- Cucumber aqueous extract 10% 2.5 liter/ha + MW at 40 DAS

Figure 1. Effect of treatments on the population of total bacteria (CFU x 10^6/g of soil) at different days after application



W1-Weedy check; W2- Hand weeding at 20 and 40 DAS; W3- Mechanical weeding (MW) at 20 and 40 DAS; W4-Imazethapyr 75 g/ha + MW at 40 DAS; W5- Cucumber aqueous extract 10% 2.5 liter/ha + MW at 40 DAS

Figure 2. Effect of treatments on the population of Actinomycetes (CFU x 10^5/g of soil) at different days after application

Table 3. Effect of treatment on pod/plant, pod length, seed/pod and test weight of greengram (pooled data of two years)

Treatment	Pods/ plant	Pod length (cm)	Seeds/pod	Test weight (g)
Weedy check	12.50	5.45	7.88	23.95
Hand weeding at 20 and 40 DAS	17.88	8.38	10.38	34.60
Mechanical weeding (MW) at 20 and 40 DAS	15.63	6.80	8.63	30.48
Imazethapyr 75 g/ha + MW at 40 DAS	16.88	7.80	10.13	32.65
Cucumber aqueous extract 10% 2.5 liter/ha + MW at 40 DAS	16.38	7.15	8.88	31.56
LSD (p=0.05)	0.64	0.31	0.91	0.76

Table 4. Effect of treatment on grain yield (t/ha), biological yield (t/ha), harvest index (%) and economics of greengram (pooled data of two years)

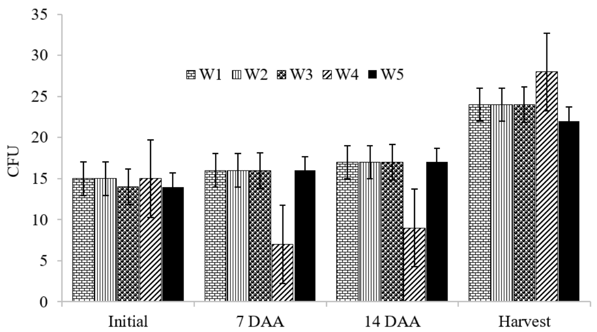
Treatment	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index (%)	Crude protein (%)	Cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C
Weedy check	0.59	3.64	21.70	18.75	26.25	35.4	9.15	1.35
Hand weeding at 20 and 40 DAS	1.37	4.87	28.13	21.24	41.25	82.2	40.95	1.99
Mechanical weeding (MW) at 20 and 40 DAS	0.84	3.95	24.81	19.33	35.25	50.4	15.15	1.43
Imazethapyr 75 g/ha + MW at 40 DAS	1.27	4.70	27.02	20.87	29.65	76.2	46.55	2.57
Cucumber aqueous extract 10% 2.5 L/ha + MW at 40 DAS	0.93	4.30	26.74	19.55	28.75	55.8	27.05	1.94
LSD (P=0.05)	0.07	0.95	NS	NS	-	-	-	-

Table 5. Pearson's correlation coefficient depicting pair-wise association between different biological parameters in greengram (pooled data of two years)

Treatment	Crude Protein (%)	Grain yield (t/ha)	Test weight	Pods/ plant	Seeds /pod	CGR 25-50 DAS	LAI 25 DAS	Nodule /plant	WCE 25 DAS
Crude Protein (%)	1								
Grain yield (t/ha)	0.993**								
Test weight	0.859**	0.912*							
Pods/plant	0.866*	0.918*	0.999**						
Seeds/pod	0.996**	0.999**	0.892*	0.898*					
CGR 25-50 DAS	0.983**	0.984**	0.894*	0.901*	0.979**				
LAI 25 DAS	0.825*	0.887*	0.993**	0.993**	0.866**	0.852**			
Nodule/plant	0.812*	0.875*	0.993**	0.989**	0.854**	0.840**	0.996**		
WCE 25 DAS	0.840*	0.897*	0.996**	0.993**	0.878*	0.864**	0.996**	0.999**	1

** Correlation is significant at the $(\sqrt{x+1})$

* Correlation is significant at the $\sqrt{x+0.5}$



W1-Weedy check; W2- Hand weeding at 20 and 40 DAS; W3- Mechanical weeding (MW) at 20 and 40 DAS; W4-Imazethapyr 75 g/ha + MW at 40 DAS; W5- Cucumber aqueous extract 10% 2.5 liter/ha + MW at 40 DAS

Figure 3. Influence of treatments on the population of fungi (CFU x 10^4/g of soil) at different days after application

flora (total bacteria, actinomycetes and fungi) in rhizosphere soil of greengram at initial stage. Though after the application of imazethapyr and cucumber aqueous extract 10%, significant variations were found between the treated and non treated plots. The population of total bacteria (**Figure 1**), actinomycetes (**Figure 2**) and fungi (**Figure 3**) decreased up to 14 DAA as compared to the observation before spraying and then increased for herbicidal treatments. Twice hand weeding, mechanical weeding and weedy check recorded steady but very slow increase of the population. The composition and dosages of chemical and botanical herbicides have been proven to have a considerable impact on soil microorganisms, with the inhibitory effect being noticeable shortly after its application. Since their concentration in soil has increased, the majority of harmful impacts on the development and activity of the microbial community often take place soon after herbicide application. The decrease in the population up to a certain period was due to competitive influence and the toxic effect as well as differential persistence periods of various herbicides in different soil ecosystems. On the other hand, the increase was affected by the commensalic or proto-cooperative influence of various micro-organisms on total bacteria, actinomycetes and fungi in the rhizosphere of greengram. For all the treatments, the microbial population recovered from initial loss and exceeded than initial counts. These results were in conformity with Adhikary *et al.* (2014).

Economics

Data in **Table 4** revealed that maximum net monetary return and benefit cost ratio was obtained from the treatment receiving imazethapyr 75 g/ha *fb* MW at 40 DAS ₹ 46.55 (x10^3/ha) and 2.57, followed by two hand weeding ₹ 40.95 (x10^3/ha) and 1.99 and B:C ratio 1.94 in cucumber aqueous extract 10% 2.5 liter/ha treatment. Whereas, the weedy check treatment registered the lowest net return ₹ 9.15 (x10^3/ha) and B:C ratio of 1.35. Though hand weeded plots registered the highest yield, it was cost-prohibitive and ineffective due to high labor cost, timely unavailability of skilled labor and high time requirement. With the timely unavailability of safer chemicals in rural areas, the aqueous extracts of cucumber leaf in combination with mechanical weeding (MW) might be an alternative and feasible option. Adhikary *et al.* (2014 and 2016) reported similar findings. The Pearson's correlation coefficient depicting pair-wise association between different biological parameters in greengram is given in Table 5.

The study concluded that the integrated weed management practices involving either application of imazethapyr 75 g/ha EPoE *fb* mechanical weeding at 40 DAS, or aqueous extract of cucumber (*Cucumis sativus* L.) plant 10% 2.5 liter/ha at PE *fb* mechanical weeding at 40 DAS might be the possible options for cost-effective weed management in greengram. Since herbicides lower the weed seed bank by killing, weakening, and/or inhibiting the propagation of weed seeds, cost-effective herbicidal management has the ability to increase the area of summer greengram that is weed-limited by bringing in significant economic benefits to the marginal farmers of the alluvial plains.

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RESEARCH ARTICLE

Evaluation of post-emergence herbicides for weed management in greengram

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ABSTRACT

A field experiment was conducted to evaluate the bio-efficacy of fomesafen 11.1% w/w + fluazifop-p-butyl 11.1% w/w (25% w/v SL) for control of complex weed flora in greengram and its residual effects on succeeding crop at GBPUA&T, Pantnagar during *Kharif* (rainy) season of 2017 and 2018. The results revealed that post-emergence application of fomesafen + fluazifop-p-butyl 25% SL applied at 250 and 312.5 g/ha being at par were found to be most effective in controlling all type of weeds in greengram. There were no phytotoxic symptoms due to any dose of fomesafen + fluazifop-p-butyl 25% SL. The highest grain yield (1.22 t/ha) was obtained with fomesafen + fluazifop-p-butyl 25% SL applied at 312.5 g/ha closely followed by its lower dose250g/ha (1.21 t/ha) and two hand weeding at 20 and 40 DAS (1.21 t/ha). Propaquizafop 10% EC at 100 g/ha and quizalofop-ethyl 5% EC at 50 g/ha kept as standard checks proved inferior.

Keywords: Bio-efficacy, Fomesafen + fluazifop-p-butyl, Greengram, Phytotoxicity, Standard checks

INTRODUCTION

India is the highest producer as well as consumer of pulses in the world. Greengram with 43.26 million ha is the third important pulse crop of India grown in nearly 8 per cent of the total pulse area of the country. In India, total production of greengram is 2.05 million tons (Anonymous 2021-22). Its seed contains 24.7% protein due to its supply of cheaper protein source, it is designated as "poor man's meat" (Potter and Hotchkiss 1997). Greengram has high digestibility and palatability; its pods are used as green vegetable. Its whole grains and split grains are used as dal and curry. Its green plants, chopped and mixed with other fodders are palatable as feed for animals. It is also used as green manuring crop, which adds nitrogen in addition to humus to the soil. It is a soil protecting crop in rainy season.

Greengram is recommended for cultivation mainly in *Kharif* season under Tarai condition in Uttarakhand, India. Weed infestation is one of the major constraints in greengram cultivation and causes 50 to 90% yield loss (Kumar *et al*. 2006). Competition with the weeds leads to 30 to 80% reduction in grain yield of greengram during summer and *Kharif* seasons while 70-80% during *Rabi* season, respectively. Algotar *et al.* (2015) reported that the weed infestation if not checked within 20 DAS, there would be a severe yield reduction to an extent of 38 per cent in contrast to 20 per cent yield reduction with unchecked weed infestation till 20 DAS in greengram. A first period of 20-40 days after sowing is crucial for crop-weed completion (Pankaj *et al.* 2017). Mechanical practices such as hand weeding and inter–culturing is effective but unavailability of labour and incessant rains during the early crop season normally limit the weeding operations. Therefore, chemical weeding under such circumstances becomes indispensable and can be a cost-effective alternative.

Application of pendimethalin and imazethapyr during pre-emergence (PE) and post-emergence (PoE), respectively, have shown promising results in greengram Singh *et al.* (2015). However, narrow time window of application often makes the PE herbicides less preferred choice among the farmers. Also, application of a single herbicide is often ineffective in controlling diverse weed flora. On the contrary, either ready or tank mixes of compatible herbicides with varying modes of action may ensure effective control of diverse weed flora and check shifting of weed flora complex and herbicide resistance Banerjee *et al.* (2018). In general, there is paucity of information on the impact of new herbicide ready mixes available in Indian market on the performance of monsoon greengram.

Under the above perspectives, the present study was formulated to evaluate the effect of new

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herbicide ready-mixes on weed density and dry matter accumulation, growth and yield of monsoon greengram and the performance of succeeding *Rabi*(mustard) crop in clay loam soil of Pantnagar, Uttarakhand.

MATERIALS AND METHODS

The field experiment was conducted at GBPUA&T, Pantnagar (29°N latitude, 27.3°E longitude and at an altitude of 243.8 m above mean sea level) during *Kharif* season of 2017 and 2018. The climate of Pantnagar is very hot in summers and cold in winters. The soil of the experimental site is clay loam in texture.

Greengram variety "*Pant Mung-5*" was sown manually with 30x10cm planting geometry in a plot size of 5.5m x 3.6m with seed rate of 15 kg/ha. Nine treatment combinations comprised of three doses of fomesafen + fluazifop-p-butyl 25% SL at 187.5, 250, and 312.5 g/ha, fomesafen 25% w/v SL 156.25 g/ha, fluazifop-p-butyl 13.4% EC 156.25 g/ha were compared with quizalofop-ethyl 5% EC at 50 g/ha and propaquizafop 10% EC at 100 g/ha as standard checks, and also twice hand weeding (20 and40 DAS) and weedy check. Herbicides were applied with knapsack sprayer fitted with flat fan nozzle using 500-liter water/ha. Phytotoxicity of Fomesafen + fluazifop-p-butyl 25% SL at 312.5 and 625.0 g/ha was studied on greengram. The experiment was laid out in randomized block design (RBD) with three replications. Thinning was done manually to maintain optimal plant population. Irrigation was applied in the field as per requirement. A recommended dose of fertilizer (20:40:30 kg NPK/ha) was applied as per package of practices of crop for the area.

Category-wise weed count and their dry biomass accumulation and total weed density, total weed dry biomass and weed control efficiency were measured at 07, 14, 21, 28, 42 DAA and at harvest by placing a quadrate of 0.25 m^2 randomly at 3 places in each plot and were subjected to square-root transformation [$\sqrt{x+0.5}$] before analysis. Crop was harvested on November 13, 2018 and left in the field for 5-7 days for sun drying. The number of plants/m^2, pods/plant, 100 grain weight, grain yield and plant height were recorded. Phytotoxic symptoms were recorded at 0, 1, 3, 7, 14 and 28 days after herbicide application at dose of 312.5 and 625 g/ha of fomesafen + fluazifop-p-butyl 25% SL by comparing it with untreated check. Carry over effect of applied herbicides were also observed on succeeding mustard crop. Succeeding mustard crop variety *Kranti* was sown in *Rabi* season of 2017-18 and 2018-19 on 12-12-2017 and 24-11-2018, respectively. Data were analyzed by using standard statistical techniques (STPR package). Treatment means were separated using the least significant difference (LSD) at the 5% level of significance. Differences were considered significant only at p=0.05.

RESULTS AND DISCUSSION

Weed flora

The major weed flora recorded in weedy check plots in greengram crop consisted of *Eleusine indica, Echinochloa colona, Digitaria sanguinalis, Dactyloctenium aegyptium* and *Panicum maximum* among grassy weeds: *Mollugo stricta, Celosia argentea, Phyllanthus niruri, Eclipta alba, Digera arvensis* and *Amaranthus viridis* as broadleaf weeds (BLWs) and *Cyperus rotundus* and *Cyperus iria* as sedges (Khairnar *et al*. 2015) also reported the similar findings.

Effect of herbicides on weed density and weed dry weight at 21 and 42 DAA

Application of various weed control treatments had significant effect over the density of weeds at 21 and 42 DAA. The efficacy of fomesafen + fluazifop-p-butyl 25% SL was further improved with the corresponding increase in the rates of application from 187.0 to 312.5 g/ha or higher rate 312.5 g/ha and proved superior over other herbicidal treatments. *Eleusine indica, Echinochloa colona, Digitaria sanguinalis, Dactyloctenium aegyptium, Trianthema monogyna, Digera arvensis, Amaranthus viridis, Eclipta alba* and *Cyperus iria* were completely controlled with application of Fomesafen + Fluazifop-p-butyl 25% SL at 312.5 and 250.0 g/ha. However, at 21 and 45 DAA the density of *Panicum maximum, Mollugo stricta, Celosia argentea, Phyllanthus niruri* and *Cyperus rotundus* was not completely controlled by Fomesafen + Fluazifop-p-butyl 25% SL applied at any doses but these are also effective in reducing the density (**Table 1-4**). On other hand, standard checks quizalofop ethyl 5% EC 50 g/ha PoE and propaquizafop 10% EC 100 g/ha as PoE caused more reduction in the density and dry weight of all type weeds as compared to weedy check plots. However, twice hand weeding at 20 and 40 DAS reduced the density and dry weight of weeds to the maximum extent over herbicidal treatments due to elimination of all sort of weeds during the course of hand weeding (Das 2008) except Fomesafen + Fluazifop-p-butyl 25% SL at 312.5 and 250.0 g/ha in the present study.

Fluazifop-p-butyl, and Fomesafen alone being selective for a certain set of weeds (Oliveria Junior 2011) did not provide satisfactory control of total weeds.

Total weed density, total weed dry biomass and weed control efficiency

Among the different herbicidal treatments, the lowest total weed density was recorded with fomesafen + fluazifop-p-butyl 25% SL at 312.5 g/ha and was significantly superior to rest of the herbicidal treatments, at all the stages of crop growth (**Table 5**). The lowest total weed dry biomass and highest weed control efficiency was recorded with application of Fomesafen + fluazifop-p-butyl 25% SL 312.5 g/ha followed by fomesafen + fluazifop-p-butyl 25% SL 250.0 g/ha amongst different herbicidal treatments at all the stages (**Table 5**). Weed-control efficiency

Table 1. Effect of different treatments on weed density and dry weight of grassy weed and sedges at 21 DAA (pooled data of two year)

Treatment	Dose (g/ha)	Grassy weeds										Sedges			
		Eleusine indica		*Echinochloa colona*		*Panicum maximum*		*Dactyloctenium aegyptium*		*Digitaria sanguinalis*		*Cyperus rotundus*		*Cyperus iria*	
		Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight
Fomesafen + fluazifop-p-butyl	187.5	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	3.1 (9.3)	1.8 (2.3)	1.2 (0.7)	1.1 (0.3)	1.0 (0.0)	1.0 (0.0)	6.0 (35.3)	2.8 (6.7)	1.0 (0.0)	1.0 (0.0)
Fomesafen + fluazifop-p-butyl	250	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	2.2 (4.0)	1.3 (0.7)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	3.5 (11.3)	1.9 (2.6)	1.0 (0.0)	1.0 (0.0)
Fomesafen + fluazifop-p-butyl	312.5	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.8 (2.7)	1.2 (0.5)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	2.8 (7.3)	1.7 (1.9)	1.0 (0.0)	1.0 (0.0)
Fomesafen	156.25	5.4 (31.3)	3.7 (14.3)	2.8 (7.3)	2.7 (6.3)	4.7 (21.3)	2.5 (5.3)	4.5 (19.3)	2.5 (5.3)	3.3 (10.7)	2.2 (3.9)	3.0 (8.0)	1.8 (2.3)	1.0 (0.0)	1.0 (0.0)
Fluazifop-p-butyl	156.25	1.5 (2.7)	1.0 (0.1)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.1)	4.3 (18.0)	2.7 (6.3)	4.3 (17.3)	2.6 (5.8)	6.4 (40.7)	2.9 (7.5)	1.0 (0.0)	1.0 (0.0)
Quizalofop-ethyl	50	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.6 (2.0)	1.3 (0.7)	1.2 (0.7)	1.1 (0.4)	1.0 (0.0)	1.0 (0.0)	4.8 (22.7)	2.7 (6.4)	3.6 (14.7)	2.5 (6.3)
Propaquizafop	100	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	3.8 (13.3)	2.2 (3.7)	1.0 (0.0)	1.0 (0.0)	1.4 (1.3)	1.2 (0.7)	3.7 (12.7)	2.6 (5.6)	3.0 (10.7)	2.0 (3.6)
Hand weeding (20&40DAS)	-	3.9 (15.3)	2.2 (3.9)	1.6 (2.0)	1.4 (1.2)	2.6 (6.0)	1.6 (1.7)	3.1 (8.7)	2.2 (3.8)	3.9 (14.7)	2.6 (5.7)	5.3 (26.7)	2.6 (5.7)	2.8 (8.0)	1.9 (2.9)
Weedy check	-	7.6 (60.7)	5.3 (28.1)	3.4 (10.7)	3.4 (10.9)	6.3 (40.7)	3.8 (14.0)	5.2 (26.0)	3.2 (9.4)	5.6 (30.7)	3.2 (9.2)	7.0 (48.0)	3.2 (9.6)	5.8 (37.3)	3.8 (14.5)
LSD (p=0.05)	-	1.19	0.69	0.43	0.27	0.88	0.47	0.46	0.20	0.19	0.23	0.53	0.19	1.32	0.68

DAS: Days after sowing; Value in parentheses were original and transformed to square root ($\sqrt{x+1}$) for analysis; Density (no./m^2); Dry weight (g/m^2)

Table 2. Effect of different treatments on weed density and dry weight of broad-leaved weed at 21 DAA (pooled data of two year)

Treatment	Dose (g/ha)	Broad-leaved weeds													
		Mollugo stricta		*Trianthema monogyna*		*Celosia argentea*		*Digera arvensis*		*Amaranthus viridis*		*Phyllanthus niruri*		*Eclipta alba*	
		Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight
Fomesafen + fluazifop-p-butyl	187.5	3.3 (10.0)	1.4 (1.0)	2.5 (5.3)	1.9 (2.7)	2.7 (6.7)	2.2 (4.3)	1.4 (1.3)	1.3 (0.9)	1.0 (0.0)	1.0 (0.0)	2.0 (3.3)	1.4 (1.0)	1.0 (0.0)	1.0 (0.0)
Fomesafen + fluazifop-p-butyl	250	2.3 (4.7)	1.2 (0.3)	1.2 (0.7)	1.1 (0.3)	1.8 (2.7)	1.5 (1.5)	1.2 (0.7)	1.1 (0.3)	1.0 (0.0)	1.0 (0.0)	1.6 (2.0)	1.2 (0.6)	1.0 (0.0)	1.0 (0.0)
Fomesafen + fluazifop-p-butyl	312.5	2.1 (4.0)	1.1 (0.3)	1.0 (0.0)	1.0 (0.0)	1.4 (1.3)	1.4 (1.1)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.4 (1.3)	1.1 (0.3)	1.0 (0.0)	1.0 (0.0)
Fomesafen	156.25	2.0 (3.3)	1.2 (0.4)	2.2 (4.0)	1.7 (2.1)	2.2 (4.0)	1.8 (2.3)	1.0 (0.0)	1.0 (0.0)	2.1 (4.0)	1.5 (1.5)	2.7 (6.7)	1.5 (1.2)	1.0 (0.0)	1.0 (0.0)
Fluazifop-p-butyl	156.25	3.8 (14.7)	1.5 (1.5)	2.6 (6.7)	2.1 (3.7)	3.8 (13.3)	2.6 (6.8)	4.5 (19.3)	2.6 (5.8)	2.9 (8.0)	1.7 (1.9)	2.7 (6.7)	1.8 (2.4)	1.4 (1.3)	1.4 (1.1)
Quizalofop-ethyl	50	4.0 (17.3)	1.6 (1.5)	3.6 (12.0)	2.7 (6.5)	4.4 (18.0)	2.7 (7.2)	4.2 (16.7)	2.5 (5.3)	2.7 (6.7)	1.7 (1.9)	2.7 (6.7)	1.6 (1.8)	1.4 (1.3)	1.4 (1.2)
Propaquizafop	100	3.7 (14.7)	1.5 (1.3)	2.5 (5.3)	1.9 (2.8)	4.6 (20.0)	2.5 (5.7)	4.3 (18.0)	2.5 (5.5)	2.5 (5.3)	1.6 (1.7)	3.0 (8.0)	1.8 (2.2)	1.4 (1.3)	1.4 (1.1)
Hand weeding (20&40DAS)	-	3.1 (11.0)	1.3 (0.8)	2.0 (3.3)	1.7 (2.0)	3.1 (8.7)	2.2 (4.1)	3.7 (12.7)	2.9 (7.9)	1.7 (2.7)	1.3 (0.7)	2.4 (4.7)	1.3 (0.7)	1.0 (0.0)	1.0 (0.0)
Weedy check	-	4.7 (23.3)	2.1 (3.6)	4.6 (20.0)	3.9 (14.4)	5.4 (28.7)	3.5 (11.9)	5.4 (28.7)	3.4 (10.3)	3.4 (11.3)	2.3 (4.4)	3.8 (14.0)	2.1 (3.7)	1.8 (2.7)	1.7 (2.3)
LSD (p=0.05)	-	1.09	0.22	0.62	0.43	0.50	0.75	0.51	0.34	0.72	0.30	0.66	0.31	0.42	0.36

DAS: Days after sowing; Value in parentheses were original and transformed to square root ($\sqrt{x+1}$) for analysis; Density (no./m^2); Dry weight (g/m^2)

(WCE) based on total dry weight varied significantly amongst the treatments. This is due to broad-spectrum control of weeds by fomesafen + fluazifop-p-butyl (Oliveria Junior 2011).

Among the different herbicidal treatments, the lowest total weed density, total weed dry biomass and highest weed control efficiency were recorded with fomesafen + fluazifop-p-butyl 25% SL at 312.5 g/ha and was significantly superior to rest of the herbicidal treatments, at all the stages of crop growth (**Table 5**).

Effect of weed control treatments on various agronomic indices in greengram

The values of weed indices like weed control efficiency (WCE), herbicide efficiency index (HEI) and weed persistency index (WPI) were inferior in weedy checks plots (**Table 5**). But ready-mix application of fomesafen + fluazifop-p-butyl 25% SL at 250 and 312.5 g/ha recorded superior values of WCE, HEI and WPI. Application of propaquizafop 100 g/ha and fomesafen 25% 156.25 g/ha also

Table 3. Effect of different treatments on weed density and dry weight of grassy weed and sedges at 42 DAA (pooled data of two year)

Treatment	Dose (g/ha)	Grassy weeds										Sedges			
		Eleusine indica		*Echinochloa colona*		*Panicum maximum*		*Dactyloctenium aegyptium*		*Digitaria sanguinalis*		*Cyperus rotundus*		*Cyperus iria*	
		Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight
Fomesafen +	187.5	1.0	1.0	1.0	1.0	2.9	2.4	1.3	1.4	1.2	1.2	4.7	2.0	1.0	1.0
fluazifop-p-butyl		(0.0)	(0.0)	(0.0)	(0.0)	(7.3)	(4.8)	(1.3)	(1.5)	(0.7)	(0.4)	(22.0)	(3.1)	(0.0)	(0.0)
Fomesafen +	250	1.0	1.0	1.0	1.0	1.9	1.5	1.0	1.0	1.0	1.0	2.6	2.0	1.0	1.0
fluazifop-p-butyl		(0.0)	(0.0)	(0.0)	(0.0)	(2.0)	(1.6)	(0.0)	(0.0)	(0.0)	(0.0)	(6.0)	(3.0)	(0.0)	(0.0)
Fomesafen +	312.5	1.0	1.0	1.0	1.0	1.5	1.5	1.0	1.0	1.0	1.0	2.2	1.9	1.0	1.0
fluazifop-p-butyl		(0.0)	(0.0)	(0.0)	(0.0)	(1.3)	(1.4)	(0.0)	(0.0)	(0.0)	(0.0)	(4.0)	(2.5)	(0.0)	(0.0)
Fomesafen	156.25	4.1	4.0	2.2	3.9	2.4	3.3	4.0	3.5	4.8	3.3	4.1	1.9	1.0	1.0
		(18.7)	(19.3)	(4.0)	(14.7)	(10.7)	(10.0)	(15.3)	(11.5)	(22.7)	(10.2)	(16.0)	(2.7)	(0.0)	(0.0)
Fluazifop-p-butyl	156.25	1.0	1.0	1.0	1.0	2.5	1.3	4.0	3.9	3.5	2.9	5.6	2.1	1.0	1.0
		(0.0)	(0.0)	(0.0)	(0.0)	(1.3)	(0.8)	(15.3)	(13.9)	(11.3)	(7.8)	(30.7)	(3.5)	(0.0)	(0.0)
Quizalofop-ethyl	50	1.0	1.0	1.0	1.0	1.7	1.8	1.2	1.2	1.0	1.0	4.5	2.1	2.3	1.8
		(0.0)	(0.0)	(0.0)	(0.0)	(4.0)	(2.3)	(0.7)	(0.5)	(0.0)	(0.0)	(20.0)	(3.4)	(4.7)	(2.5)
Propaquizafop	100	1.6	1.6	1.0	1.0	2.2	2.3	1.2	1.2	1.2	1.2	3.9	2.1	2.1	1.6
		(2.0)	(2.0)	(0.0)	(0.0)	(4.7)	(4.6)	(0.7)	(0.5)	(0.7)	(0.4)	(14.0)	(3.3)	(4.7)	(2.1)
Hand weeding	-	1.0	1.0	1.0	1.0	2.3	1.3	3.9	3.1	3.8	3.5	3.3	1.9	1.0	1.0
(20&40DAS)		(0.0)	(0.0)	(0.0)	(0.0)	(2.0)	(0.7)	(14.7)	(9.5)	(13.3)	(11.1)	(10.0)	(2.7)	(0.0)	(0.0)
Weedy check	-	5.9	7.2	2.9	4.9	1.8	3.9	5.0	4.5	5.8	4.9	6.2	2.6	3.7	2.7
		(36.0)	(59.0)	(7.3)	(22.9)	(16.7)	(14.5)	(24.0)	(19.3)	(32.7)	(23.1)	(37.3)	(6.0)	(13.3)	(6.2)
LSD (p=0.05)	-	1.04	1.48	0.12	0.38	NS	0.52	0.63	0.66	0.47	0.34	0.58	0.23	0.71	0.41

DAS: Days after sowing; Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis; Density (no./m^2); Dry weight (g/m^2)

Table 4. Effect of different treatments on weed density and dry weight of broad-leaved weed at 42 DAA (pooled data of two year)

Treatment	Dose (g/ha)	Broad-leaved weeds													
		Mollugo stricta		*Trianthema monogyna*		*Celosia argentea*		*Digera arvensis*		*Amaranthus viridis*		*Phyllanthus niruri*		*Eclipta alba*	
		Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight	Density	Dry weight
Fomesafen +	187.5	2.9	1.4	1.6	1.9	3.1	2.2	1.5	1.3	1.0	1.0	2.4	1.4	1.0	1.0
fluazifop-p-butyl		(7.3)	(1.0)	(2.0)	(2.7)	(8.7)	(4.3)	(2.0)	(0.9)	(0.0)	(0.0)	(4.7)	(1.0)	(0.0)	(0.0)
Fomesafen +	250	2.7	1.2	1.0	1.1	2.4	1.5	1.4	1.1	1.0	1.0	2.0	1.2	1.0	1.0
fluazifop-p-butyl		(6.7)	(0.3)	(0.0)	(0.3)	(4.7)	(1.5)	(1.3)	(0.3)	(0.0)	(0.0)	(3.3)	(0.6)	(0.0)	(0.0)
Fomesafen +	312.5	2.4	1.1	1.0	1.0	1.8	1.4	1.0	1.0	1.0	1.0	1.6	1.1	1.0	1.0
fluazifop-p-butyl		(4.7)	(0.3)	(0.0)	(0.0)	(2.7)	(1.1)	(0.0)	(0.0)	(0.0)	(0.0)	(2.0)	(0.3)	(0.0)	(0.0)
Fomesafen	156.25	3.1	1.2	1.4	1.7	2.2	1.8	1.0	1.0	2.1	1.5	2.0	1.5	1.0	1.0
		(8.7)	(0.4)	(1.3)	(2.1)	(4.0)	(2.3)	(0.0)	(0.0)	(4.0)	(1.5)	(3.3)	(1.2)	(0.0)	(0.0)
Fluazifop-p-butyl	156.25	3.6	1.5	2.5	2.1	4.0	2.6	3.6	2.6	1.8	1.7	2.9	1.8	1.0	1.4
		(14.7)	(1.5)	(5.3)	(3.7)	(15.3)	(6.8)	(13.3)	(5.8)	(2.7)	(1.9)	(8.0)	(2.4)	(0.0)	(1.1)
Quizalofop-ethyl	50	3.8	1.6	2.6	2.7	3.5	2.7	3.5	2.5	1.3	1.7	2.8	1.6	1.0	1.4
		(14.0)	(1.5)	(6.0)	(6.5)	(12.0)	(7.2)	(12.0)	(5.3)	(1.3)	(1.9)	(7.3)	(1.8)	(0.0)	(1.2)
Propaquizafop	100	4.0	1.5	2.0	1.9	4.4	2.5	3.9	2.5	2.1	1.6	2.7	1.8	1.0	1.4
		(16.0)	(1.3)	(3.3)	(2.8)	(18.0)	(5.7)	(14.7)	(5.5)	(4.0)	(1.7)	(7.3)	(2.2)	(0.0)	(1.1)
Hand weeding	-	1.7	1.3(0.8)	1.0	1.7	1.4	2.2	3.0	2.9	2.3	1.3	1.4	1.3	1.0	1.0
(20&40DAS)		(2.7)		(0.0)	(2.0)	(1.3)	(4.1)	(8.0)	(7.9)	(5.3)	(0.7)	(1.3)	(0.7)	(0.0)	(0.0)
Weedy check	-	4.9	2.1(3.6)	3.3	3.9	5.1	3.5	4.8	3.4	3.3	2.3	3.8	2.1	1.8	1.7
		(24.7)		(10.0)	(14.4)	(25.3)	(11.9)	(22.7)	(10.3)	(10.0)	(4.4)	(13.3)	(3.7)	(2.7)	(2.3)
LSD (p=0.05)	-	1.07	0.22	0.48	0.43	0.59	0.75	0.77	0.34	0.75	0.30	0.80	0.31	0.25	0.36

DAS: Days after sowing; Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis; Density (no./m^2); Dry weight (g/m^2)

performed well but the combined application of fomesafen + fluazifop-p-butyl 25% SL at 250 and 312.5 g/ha and twice hand weeding at 20 and 40 DAS proved better for their weed indices.

Yield and yield attributing characters

Yield and yield attributing characters in treated plots were found significantly superior to weedy check (**Table 6**). Among the different weed control treatments, fomesafen + fluazifop-p-butyl 25% SL at 312.5 g/ha was found superior in attaining the yield and yield attributing characters. Yadav *et al.* 2022 and Piragi 2022 were also reported similar findings. The seed index (3.6 g) was recorded highest with twice hand weeding. The average grains/pod (6.8) and pods/plant (34.1) were recorded highest with fomesafen + fluazifop-p-butyl 25% SL at 312.5 g/ha.

Fomesafen + fluazifop-p-butyl 25% SL at higher dose (312.5 g/ha) resulted into highest seed yield (1.30 t/ha), however, it was at par with lower dose 250 g/ha and two hand weeding at 20 and 40 DAS. This might be owing to higher weed control efficiencies of these treatments that reduced the inter-specific competition for resources and allowed the crop to grow to its best potential which in turn positively influenced the biomass production and yield of crop (Lal *et al.* 2017).

Effect on succeeding crop

Phytotoxicity on succeeding mustard crop: No any phytotoxicity systems were observed on mustard crop regarding different doses of herbicides applied on Greengram crop.

Effect of plant population: In succeeding crop, the plant population of Mustard was not influenced significantly due to various weed control treatments applied on greengram.

Effect on yield and yield attributing characters: All yield and yield attributing characters were not influenced significantly due to weed control treatments (**Table 7**) and their differences were statistically non-significant. Application of fomesafen 11.1% w/w + fluazifop-p-butyl 11.1% w/w SL against weeds in greengram during *Kharif* season was observed safe for growing Mustard crop in *Rabi* season.

Conclusions

Fomesafen 11.1% w/w + fluazifop-p-butyl 11.1% w/w 25% SL at 250 to 312.5 g/ha being better than the standard check provided efficient control of complex weed flora in greengram resulted into improved crop productivity and profitability.

Table 5. Effect of different treatments on total weed density, dry weight, WCE, HEI and WPI (pooled data of two year)

Treatment	Dose (g/ha)	Total weed density (no./m^2)		Total weed dry weight (g/m^2)		WCE (%)		HEI		WPI	
		21 DAA	42 DAA	21 DAA	42 DAA	21 DAA	42 DAA	21 DAA	42 DAA	21 DAA	42 DAA
Fomesafen + fluazifop-p-butyl	187.5	8.5(72.0)	7.5(56.0)	4.5(19.1)	5.5(29.4)	86.9	86.5	2.79	2.77	0.69	0.65
Fomesafen + fluazifop-p-butyl	250	5.2(26.0)	5.0(24.0)	2.7(6.4)	3.7(13.0)	95.6	93.7	9.94	7.47	0.64	0.67
Fomesafen + fluazifop-p-butyl	312.5	4.1(16.7)	3.9(14.7)	2.2(4.1)	3.0(8.0)	97.2	96.0	16.83	13.26	0.65	0.67
Fomesafen	156.25	10.9(120.0)	10.5(108.7)	6.7(44.9)	9.2(85.1)	69.3	62.1	1.08	0.87	0.98	0.96
Fluazifop-p-butyl	156.25	12.2(148.7)	10.9(118.0)	6.6(42.9)	8.2(66.2)	70.5	69.3	0.95	0.94	0.75	0.69
Quizalofop-ethyl	50	10.9(118.7)	9.1(82.0)	6.3(39.3)	7.1(50.2)	73.0	77.1	1.15	1.37	0.87	0.75
Propaquizafop	100	10.5(110.7)	9.5(90.0)	5.9(33.8)	7.0(47.7)	76.8	77.3	1.49	1.62	0.80	0.65
Hand weeding (20&40DAS)	-	11.2(124.3)	7.7(58.7)	6.5(41.1)	5.9(34.1)	71.8	84.2	-	-	-	-
Weedy check	-	19.6(382.7)	16.6(276.0)	12.1(146.4)	14.9(224.2)	0.0	0.0	-	-	-	-
LSD (p=0.05)	-	1.06	0.88	0.67	0.99						

DAS: Days after sowing; Value in parentheses were original and transformed to square root ($\sqrt{x+1}$) for analysis.

Table 6. Effect of treatment on yield and yield attributes (pooled data of two year)

Treatment	Dose (g/ha)	Plant height (cm)	Plants (no. /m^2)	Yield attributes: Pods / plant	Yield attributes: Grain/ pod	Yield attributes: 100 Seed weight (g)	Seed yield (t/ha)		
							2017	2018	Pooled
Fomesafen + fluazifop-p-butyl	187.5	62.6	42.9	28.1	6.2	3.4	1.13	1.02	1.07
Fomesafen + fluazifop-p-butyl	250	65.2	48.1	30.3	6.2	3.4	1.27	1.14	1.21
Fomesafen + fluazifop-p-butyl	312.5	58.1	50.2	34.1	6.8	3.4	1.33	1.26	1.30
Fomesafen	156.25	67.2	41.4	25.4	5.8	3.3	1.02	1.03	1.02
Fluazifop-p-butyl	156.25	65.0	37.8	27.2	6.3	3.3	0.86	1.03	0.95
Quizalofop-ethyl	50	67.9	39.9	27.0	6.3	3.4	1.00	0.98	0.99
Propaquizafop	100	65.4	39.9	27.9	5.7	3.4	1.04	1.04	1.04
Hand weeding (20 and 40 DAS)	-	65.2	42.4	28.3	6.2	3.6	1.22	1.20	1.21
Weedy check	-	68.5	34.7	23.4	5.6	3.4	0.60	0.77	0.68
LSD (p=0.05)	-	NS	6.87	4.08	0.47	NS	0.34	0.13	0.19

DAS: Days after sowing

Table 7. Effect of treatments on yield and yield attributes of succeeding mustard crop (pooled data of two year)

Treatment	Dose (g/ha)	Plants/ m^2	No. of pods/plant	1000 grain weight (g)	Grain yield (kg/ha)		
					2017	2018	Pooled
Fomesafen + fluazifop-p-butyl	312.5	44.4	118.5	3.1	909	937	923.0
Fomesafen + fluazifop-p-butyl	625	47.7	125.4	3.1	934	990	962.1
Weedy check	-	52.2	130.2	3.3	957	1005	981.1
LSD (p=0.05)	-	NS	NS	NS	NS	NS	NS

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RESEARCH ARTICLE

Complex weed flora management through herbicides in nursery and transplanted onion

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ABSTRACT

Onion nursery is severely affected by the weed which hampers the growth of seedlings and further delayed in transplanting and thereby yield. For obtaining potential yield of onion, producing and transplanting of healthy seedlings and timely control of complex weed flora is necessary in onion nursery. An experiment was carried out during two consecutive *Rabi* (winter) season of the year 2020-21 and 2021-22 at B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat (India). In this study, total 12 different treatments each in nursery and in transplanted onion were tested in a randomized block design (RBD) having three replications. Early post-emergence application (EPoE) of propaquizafop + oxyfluorfen (pre-mix) 43.75 + 105 g/ha, oxyfluorfen 80 g/ha EPoE, pendimethalin 300 g/ha as pre-emergence (PE) and twice hand weeding at 15 and 30 days after sowing (DAS) significantly reduced the dry biomass of weeds, recorded higher weed control efficiency, fresh weight of 100 seedlings, higher number of transplantable seedlings and better economic returns than rest of the treatments. All the herbicides applied in onion nursery were found safe for succeeding wheat, chickpea and mustard crop under bioassay study. In transplanted onion, pre-plant incorporation of pendimethalin 580.5 g/ha followed by (*fb)* oxyfluorfen 120 g/ha applied as post-emergence (PoE) and pre-emergence (PE) application of oxyfluorfen 120 g/ha *fb* propaquizafop + oxyfluorfen 43.75 +105 g/ha applied as post-emergence and propaquizafop + oxyfluorfen 43.75 +105 g/ha as post-emergence recorded significantly lower weed dry biomass, higher weed control efficiency, onion bulb yield, net return and benefit cost ratio.

Keywords: Herbicide, Onion nursery, Phytotoxicity, Seedling, Transplanted onion, Weed management

INTRODUCTION

Onion (*Allium cepa*) is an important vegetable cum spice crop, serving as a staple ingredient in many Indian dishes. The demand for onions in India is very high and the crop is an important source of income for many farmers in the country. It can be grown mostly by the transplanting of seedling raised in the nursery beds. hence, transplanting of healthy seedling is required for better establishment of plant and obtaining higher bulb production. Among various factor affecting growth of onion seedlings, weeds pose greater role, as weed compete for available resources which leads to curtail the uptake of nutrient by seedlings and there by the growth of seedlings become poor and produced weak seedlings. Further, onion nursery is heavily infested by the weeds due to its slow growth, non-branching habit and very less and erect plant canopy. Frequent irrigation and incorporation of FYM in the nursery field provide congenial condition for early germination and luxuriant growth of weed (Sharma *et al.*, 2009). Various approaches have been tried to control the weeds wherein, hand weeding is effective, but it is time consuming and uneconomical due to closer spacing and shallow root system of the crop and may pose the disease problem due to mechanical injury to the seedlings during hand weeding process in the main field. Therefore, weed management in nursery is important to produced vigorous and healthy onion seedling. Further, transplanted onion exhibits greater susceptibility to weed competition as compared to the other crops due to its inherent characteristics such as their slow growth, short stature, shallow roots and lack of dense foliage (Dhananivetha *et al.* 2017). Crop losses due to weeds vary from 30 to 95% in onion (Kumar 2014) and the critical period of crop-weed competition ranges from 30 to 40 days (Sathyapriya *et al.* 2017). Ramalingam *et al.* (2013) observed that reduction in onion bulb yield depends on intensity and duration of weed growth but average yield reduction was observed to the tune of 40-80% in weedy check. In the present-day situation, number of herbicides available in the market for effective control of complex weed flora in various crops with

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high potency and environmental safety. The combine application of pre-and post-emergence herbicide is one of the options left with the farmers to eliminate crop weed competition at early and later stages of the crop and to achieve higher weed control efficiency. Looking to this, use of herbicides is the best option to raise weed free nursery and also provide better control of weeds in transplanted onion crop thus, the present study was planned to assess the efficacy of herbicides against complex weed flora in onion nursery and transplanted onion.

MATERIALS AND METHODS

An experiment was carried out during two consecutive *Rabi* (winter) season of 2020-21 and 2021-22 under AICRP on Weed Management operating at B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat. The soil of the experimental field was low in organic carbon (0.38%) and medium in available phosphorous (30.58 kg/ha) and high in potassium (281.3 kg/ha). In the nursery experiment, twelve weed management practices consisted of pendimethalin 38.7% CS 200 g/ha as pre-plant incorporation (PPI), pendimethalin 38.7% CS 300 g/ha PPI, pendimethalin 30% EC 200 g/ha as pre-emergence (PE), pendimethalin 30% EC 300 g/ha PE, oxyfluorfen 23.5% EC 80 g/ha PE, oxyfluorfen 23.5% EC 120 g/ha PE, oxadiargyl 6% EC 42 g/ha PE, oxadiargyl 6% EC 60 g/ha PE, oxyfluorfen 23.5% EC 80 g/ha early post-emergence (EPoE), propaquizafop 5%+ oxyfluorfen 12% w/w EC (pre-mix) 43.75 + 105 g/ha EPoE, hand weeding at 15 and 30 DAS and weedy check were laid out in randomized block design with three replications. While in transplanted onion experiment, twelve weed management practices consisted of pendimethalin 38.7% CS 580.5 g/ha PPI, pendimethalin 38.7% CS 580.5 g/ha PPI followed by *(fb)* oxyfluorfen 23.5% EC 120 g/ha post-emergence (PoE), pendimethalin 38.7% CS 580.5 g/ha PPI *fb* oxadiargyl 6% EC 75 g/ha PoE, oxyfluorfen 23.5% EC 120 g/ha PE *fb* clodinafop 12.25% + oxyfluorfen 14.7% EC (pre-mix) 122.5+147 g/ha PoE, oxadiargyl 6% EC 75 g/ha PE *fb* clodinafop 12.25% + oxyfluorfen 14.7% EC (pre-mix) 122.5+147 g/ha PoE, oxyfluorfen 23.5% EC 120 g/ha PE *fb* propaquizafop 5% + oxyfluorfen 12% w/w EC (pre-mix) 43.75 +105 g/ha PoE, oxyfluorfen 23.5% EC 150 g/ha PoE, oxadiargyl 6% EC 90 g/ha PoE, clodinafop 12.25% + oxyfluorfen 14.7% EC (pre-mix) 122.5+147 g/ha PoE, propaquizafop 5% + oxyfluorfen 12% w/w EC (pre-mix) 43.75 +105 g/ha PoE, hand weeding at 20 and 40 DATP and weedy check were laid out in randomized block design with three replications. onion cv. *'Gujarat Anand White Onion 2'* were sown in the nursery on 6 and 1 November, 2020 and 2021, respectively keeping spacing of 10 cm between row. The nursery was raised for 45 days during both the years and observations was taken upto 45 days and then bioassay study was taken keeping as such layout. PPI, pre- and post-emergence herbicides were applied by using battery operated knapsack sprayer fitted with flat-fan nozzle by mixing in 500 litre of water/ha as per treatments. The crop was fertilizer with 50 kg N, 25 kg P and 25 kg K/ha in the form of urea, single super phosphate and murate of potash, respectively. The rest of the recommended package of practices was adopted to raise the crop. The seedlings were uprooted on 21 and 16 December 2020 and 2021, respectively.

Whereas, healthy seedling obtained from the onion nursery experiment were transplanted on 18 and 21 December, 2020 and 2021, respectively keeping spacing of 15 x 10 cm. The crop was harvested on 22 and 24 April, 2021 and 2022, respectively. PPI, Pre- and post-emergence herbicides were applied by using battery operated knapsack sprayer fitted with flat-fan nozzle by mixing in 500 litre of water/ha as per treatments. The crop was fertilizer with 100 kg N, 75 kg P and 75 kg K/ha in the form of urea, single super phosphate and murate of potash, respectively. The rest of the recommended package of practices was adopted to raise the crop. Density and dry weight of weeds were recorded from randomly selected four spots by using 0.25 m^2 iron quadrate from net plot through destructive sampling from both the experiment. Weed control efficiency (WCE) was calculated on the basis of standard formula as suggested by Maity and Mukherjee (2011). The yield reduction (%) owing to the presence of weeds was estimated by using the formula suggested by Kumar and Gill (1969) and expressed as Weed Index (WI). Other growth and yield attributing observation were also recorded from net plot area. Before statistical analysis, the data on weed dry biomass were subjected to square root ($\sqrt{x+1}$) transformation to improve the homogeneity of the variance (ANOVA). Data on various observations during the experiment period was statistically analysed as per the standard procedure developed by Cochran and Cox (1957).

RESULTS AND DISCUSSION

Nursery experiment

Effect on weed: It was observed from the two years' experimentation that dominance of dicot weed was recorded at 15 DAS of onion nursery in which

Chenopodium album (68.1%), *Melilotus indica* (13.2%), *Chenopodium murale* (8.34%) and *Trianthema monogyna* (1.50%) as dicot while *Eleusine indica* (3.13%), *Digitaria sanguinalis* (1.17%), *Setaria glauca* (1.11%) and *Dactyloctenium aegyptium* (0.72%) as monocot weed dominated in the field.

Significantly lower dry biomass of monocot and total weed (1.64 and 3.15 g/m^2, respectively) and dicot weed (1.87 g/m^2) was recorded at 45 days after sowing (DAS) under propaquizafop + oxyfluorfen (PM) 43.75+105 g/ha early post-emergence (EPoE) and twice hand weeding at 15 and 30 DAS, respectively but it remains statistically at par with oxyfluorfen 120 g/ha PE, pendimethalin 300 g/ha PE and oxadiargyl 60 g/ha (**Table 1**). Early post-emergence application of oxyfluorfen 80 g/ha reduced the dry matter of dicot weed significantly as compared to pre-emergence application at 80 and 120 g/ha. Pre-emergence application of pendimethalin 300 g/ha reduced the dry matter production of total weeds as compared to pre-plant incorporation at 200 and 300 g/ha. The results confirm the findings of Sharma *et al.* (2009). Application of pendimethalin either pre-plant incorporation or pre-emergence at both 300 g/ha recorded higher weed control efficiency of dicot weed (71.9 to 91.0%) as compared to WCE of monocot weed (57.5 to 70.9%). Similarly, pre-emergence application of oxyfluorfen recorded more than 92% weed control efficiency of monocot weed at 80 and 120 g/ha while early post-emergence application of oxyfluorfen 80 g/ha recorded 92.5% weed control efficiency of dicot weed. As dominancy of dicot weed was more in onion nursery hence, application of oxyfluorfen as early post-emergence was better than pre-emergence application. Under twice hand weeding, complete removal of weeds resulted in the highest weed control efficiency. Similar line of findings was also reported by Sathyamoorthy *et al.* (2022).

Phytotoxicity: Based on the visual observation, it was noticed that application of different herbicides showed slightly phytotoxic effect on onion seedlings at 7 days after herbicide application. Pendimethalin applied either as PPI or PE showed wilting symptoms at 7 days after herbicide application (DAHA) but recovered at 14 DAHA. Pre-emergence and early post-emergence application of oxyfluorfen showed leaf injury and necrosis symptoms on onion seedlings up to 14 DAHA. Further, application of oxyfluorfen 80 g/ha EPoE and propaquizafop + oxyfluorfen (PM) 43.75 + 105 g/ha EPoE showed slightly toxic up to 7 days after herbicide application (DAHA) and later on the seedlings were recovered from the toxicity.

Effect on seedling: Twice hand weeding carried out at 15 and 30 DAS performed better by recording significantly higher plant stand (908/m^2), fresh weight of 100 seedlings (352 g) and number of transplantable seedling (837/m^2), but it was statistically at par with the seedlings raised with the application of propaquizafop + oxyfluorfen (PM) 43.75+105 g/ha EPoE, oxyfluorfen 80 g/ha EPoE and pendimethalin 300 g/ha PE at 45 DAS. It may be concrete that keeping the onion nursery free of weeds either through mechanical or chemical method will result in production of healthiest seedlings. Sathyamoorthy *et al.* (2022) also recorded higher and healthy transplantable seedlings under hand weeding

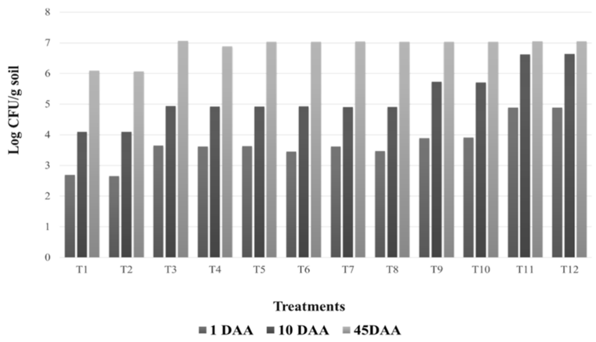
Table 1. Dry biomass of weeds and WCE as influenced by weed management practices in onion nursery at 45 DAS (pooled data for two years)

Treatment	Weed dry biomass of monocot (g/m^2)	Weed dry biomass dicot (g/m^2)	Weed dry biomass total (g/m^2)	WCE (%) Monocot weed	Dicot weed	Total weed	Weed index (%)
Pendimethalin 200 g/ha PPI	4.27(17.7)	7.99(63.5)	9.00(81.0)	57.5	71.9	69.8	30.1
Pendimethalin 300 g/ha PPI	3.73(13.7)	6.86(46.9)	7.79(60.7)	67.1	79.3	77.4	35.2
Pendimethalin 200 g/ha PE	3.86(14.5)	6.37(40.5)	7.46(55.0)	65.1	82.1	79.5	21.6
Pendimethalin 300 g/ha PE	3.56(12.1)	4.46(20.3)	5.72(32.4)	70.9	91.0	87.9	6.9
Oxyfluorfen 80 g/ha PE	1.95(3.00)	9.26(85.9)	9.41(88.9)	92.8	62.0	66.8	43.1
Oxyfluorfen 120 g/ha PE	1.77(2.25)	8.10(67.0)	8.23(69.2)	94.6	70.4	74.2	36.7
Oxadiargyl 42 g/ha PE	4.21(19.2)	7.78(63.2)	8.81(82.4)	53.9	72.0	69.3	26.2
Oxadiargyl 60 g/ha PE	3.37(13.3)	6.41(48.1)	7.16(61.3)	68.0	78.7	77.1	28.9
Oxyfluorfen 80 g/ha EPoE	4.49(19.2)	4.05(17.0)	6.03(36.2)	53.9	92.5	86.5	6.1
Propaquizafop + oxyfluorfen 43.75 + 105 g/ha EPoE	1.64(1.75)	2.86(7.55)	3.15(9.30)	95.8	96.7	96.5	2.9
Hand weeding at 15 and 30 DAS	3.17(10.7)	1.87(2.80)	3.54(13.5)	74.3	98.8	95.0	-
Weedy check	6.35(41.6)	14.8(226)	16.1(268)	-	-	-	93.9
LSD (p=0.05)	1.60	3.70	3.65	-	-	-	-
CV%	15.4	11.5	10.2	-	-	-	-

Note: Data subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are means of original values.

method. Significantly the lowest plant stand, fresh weight of 100 seedlings and number of transplantable seedlings was recorded under weedy check. Plant height of onion seedling showed non-significant effect (**Table 2**). In general, all the herbicidal treatments significantly improved the fresh weight of 100-seedling and overall transplantable seedlings as compared to the unweeded control. This may be due to the reduced crop competition due to less germination of weeds under pre-emergence herbicide while early post-emergence herbicide controls the germinated weeds effectively. Significant reduction in total number of seedlings was recorded in pre-emergence application of oxyfluorfen at 80 and 120 g/ha due to their phytotoxic effect. Significantly the lowest plant stand, fresh weight of 100 seedlings and number of transplantable seedlings was observed under weedy check. This may be attributed to severe crop weed competition at critical stages resulting in unfavourable environment for growth and development of onion seedlings. The results are in accordance with the results of Sharma *et al.* (2009).

Microbial study: Initially there was some harmful effect of herbicides on soil microbial population, but gradually it was reduced (**Figure 1**). However, application of pendimethalin 200 g/ha and 300 g/ha as pre-plant incorporation (PPI) suppression effect on microbial population even at 45 days after sowing of onion seed. Application of pendimethalin also affects soil microorganisms. The initial reduction of soil microorganisms after application of pendimethalin into soil and stimulation of soil microorganisms at 50 and 75 days after pendimethalin application was reported by Nayak *et al.* (1994).



T_1: Pendimethalin 200 g/ha PPI; T_2: Pendimethalin 300 g/ha PPI; T_3: Pendimethalin 200 g/ha PE; T_4: Pendimethalin 300 g/ha PE; T_5: Oxyfluorfen 80 g/ha PE; T_6: Oxyfluorfen 120 g/ha PE; T_7: Oxadiargyl 42 g/ha PE; T_8: Oxadiargyl 60 g/ha PE; T_9: Oxyfluorfen 80 g/ha EPoE; T_{10}: Propaquizafop + oxyfluorfen 43.75 + 105 g/ha EPoE; T_{11}: Hand weeding at 15 and 30 DAS and T_{12}: Weedy check

Figure 1. Total soil microbial count as influenced by weed management practices in onion nursery

Economics: Economics of various weed management practices in 1000 m^2 area of onion nursery indicated that maximum gross return of ₹ 2,51,100 was achieved under twice hand weeding at 15 and 30 DAS followed by propaquizafop + oxyfluorfen (PM) 43.75 + 105 g/ha EPoE (₹ 2,43,900), oxyfluorfen 80 g/ha EPoE (₹ 2,35,800) and pendimethalin 300 g/ha PE (₹ 233700). While maximum net return of ₹ 2,24,230 and benefit cost ratio of 12.4 was observed under propaquizafop + oxyfluorfen 12 (PM) 43.75 + 105 g/ha EPoE which was followed by oxyfluorfen 80 g/ha EPoE, pendimethalin 300 g/ha PE and twice hand weeding at 15 and 30 DAS.

Transplanted onion experiment

Effect on weed: Based on the two years of experimentation, it was noticed that *Eleusine indica*,

Table 2. Growth, number of seedlings and economics as influenced by weed management practices in onion nursery (pooled data for two years)

Treatment	Plant stand (no./m^2) at 45 DAS	Height of onion seedling (cm)		Fresh weight (g) of 100 seedlings at 45 DAS	Transplantable seedlings (no./m^2) at 45 DAS	1000 m^2 area				B:C
		30 DAS	45 DAS			Transplantable onion seedlings	Total cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	
Pendimethalin 200 g/ha PPI	691	22.2	41.3	302	585	585000	19.46	175.50	156.04	9.02
Pendimethalin 300 g/ha PPI	707	21.3	40.8	299	542	542000	19.49	162.60	143.11	8.34
Pendimethalin 200 g/ha PE	858	23.8	41.0	299	656	706000	19.45	196.80	177.35	10.1
Pendimethalin 300 g/ha PE	877	23.2	39.6	307	779	779000	19.47	233.70	214.23	12.0
Oxyfluorfen 80 g/ha PE	706	22.7	38.1	262	476	476000	19.51	142.80	123.29	7.32
Oxyfluorfen 120 g/ha PE	698	21.6	37.8	259	530	530000	19.56	159.00	139.44	8.13
Oxadiargyl 42 g/ha PE	738	22.3	40.6	306	618	618000	19.50	185.40	165.90	9.51
Oxadiargyl 60 g/ha PE	732	22.2	39.3	314	595	595000	19.54	178.50	158.96	9.14
Oxyfluorfen 80 g/ha EPoE	890	24.5	39.4	333	786	786000	19.51	235.80	216.9	12.1
Propaquizafop + oxyfluorfen 43.75 + 105 g/ha EPoE	894	24.3	38.2	343	813	813000	19.67	243.90	224.23	12.4
Hand weeding at 15 and 30 DAS	908	25.1	41.5	352	837	837000	27.98	251.10	223.12	8.97
Weedy check	507	25.6	43.2	122	50.7	50700	19.31	15.21	-4.10	0.79
LSD (p=0.05)	131.0	1.77	NS	28.5	145	-	-	-	-	-
CV%	9.1	7.3	8.4	8.9	13.1	-	-	-	-	-

Note: Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values

Asphodelus tenuifolius, *Dactyloctenium aegyptium*, *Setaria glauca* and *Digitaria sanguinalis* as monocot weed while *Chenopodium album*, *Melilotus indica*, *Chenopodium murale* and *Boerhavia erecta* as dicot weed dominated in the field as per mean results.

All the herbicidal treatments significantly influenced the dry matter production of monocot, dicot and total weeds (**Table 3**). Significantly lower dry matter of monocot weed was recorded under oxyfluorfen 120 g/ha as pre-emergence (PE) followed by (*fb)* clodinafop + oxyfluorfen 122.5+147 g/ha as post-emergence (PoE) followed by oxadiargyl 75 g/ha as PE *fb* clodinafop + oxyfluorfen 122.5+147 g/ha as PoE, pendimethalin 580.5 g/ha as pre-plant incorporation (PPI) *fb* oxyfluorfen 120 g/ha PoE, oxyfluorfen 120 g/ha PE *fb* propaquizafop + oxyfluorfen 43.75 +105 g/ha PoE, clodinafop + oxyfluorfen 122.5+147 g/ha PoE, propaquizafop + oxyfluorfen 43.75 +105 g/ha PoE but were statistically at par with each other. This indicated that integration of more than one herbicide as sequential application provide excellent control of monocot weed as compared to alone application of herbicide. Lower dry biomass of weeds due to sequential application of herbicide in onion was also reported by Angmo and Chopra (2020). Whereas, significantly lower dry matter of dicot weed was noticed in pre-plant incorporation of pendimethalin 580.5 g/ha PPI *fb* oxyfluorfen 120 g/ha PoE followed by pendimethalin 580.5 g/ha PPI *fb* oxadiargyl 6% EC 75 g/ha PoE, oxyfluorfen 120 g/ha PE *fb* clodinafop + oxyfluorfen 122.5+147 g/ha PoE, oxadiargyl 75 g/ha PE *fb* clodinafop + oxyfluorfen 122.5+147 g/ha PoE and oxyfluorfen 120 g/ha PE *fb* propaquizafop 5% + oxyfluorfen 43.75 + 105 g/ha PoE. Comparatively, pre-plant incorporation of pendimethalin 580.5 g/ha as PPI *fb* oxyfluorfen 120 g/ha as PoE provide effective control of monocot and dicot weeds hence, dry matter of total weed was recorded significantly lower as compared to other treatment. Application of pendimethalin, oxadiargyl and oxyfluorfen as pre-emergence followed by post-emergence application of herbicide provide better control of monocot weed as compared to dicot weed. The highest weed biomass was noted in the weedy check due to the increased weed density was also observed by Hembrom *et al.* (2023) in onion.

Weed control efficiency of monocot, dicot and total weed in different treatments varied from 37.8 to 95.8, 91.4 to 98.9 and 87.8 to 98.0% at harvest, respectively (**Table 3**). In general, all the herbicide provides better control of dicot weed as compared to monocot weed which reflected in recording higher weed control efficiency. Pre-plant incorporation of pendimethalin 580.5 g/ha *fb* oxyfluorfen 120 g/ha as PoE provide higher weed control efficiency of 98.0% which was closely followed by pendimethalin 580.5 g/ha PPI *fb* oxadiargyl 75 g/ha PoE and oxadiargyl 75 g/ha PE *fb* clodinafop + oxyfluorfen 122.5+147 g/ha PoE. These results are in accordance with the results reported by Sampat *et al.* (2014).

Weed index denotes the yield losses due to presence of weeds and the highest values of weed index were recorded in weedy check to the tune of 89%. James and Harlen (2010) reported that uncontrolled weed growth caused 49-86% reduction

Table 3. Dry biomass of weeds and WCE as influenced by weed management practices in transplanted onion at harvest (pooled data for two years)

Treatment	Weed dry biomass of monocot (g/m^2)	Weed dry biomass dicot (g/m^2)	Weed dry biomass total (g/m^2)	WCE (%) Monocot weed	WCE (%) Dicot weed	WCE (%) Total weed	Weed index (%)
Pendimethalin 580.5 g/ha PPI	4.44(19.7)	6.65(44.6)	8.37(70.7)	77.9	93.8	91.3	13.3
Pendimethalin 580.5 g/ha PPI *fb* oxyfluorfen 120 g/ha PoE	2.51(7.65)	2.88(8.17)	3.72(15.8)	91.4	98.9	98.0	-
Pendimethalin 580.5 g/ha PPI *fb* oxadiargyl 75 g/ha PoE	2.36(6.70)	3.26(10.4)	3.93(17.1)	92.5	98.6	97.9	13.3
Oxyfluorfen 120 g/ha PE *fb* clodinafop + oxyfluorfen (PM) 122.5+147 g/ha PoE	1.94(3.78)	5.97(35.9)	6.24(39.7)	95.8	95.0	95.1	13.8
Oxadiargyl 75 g/ha PE *fb* clodinafop + oxyfluorfen (PM) 122.5+147 g/ha PoE	2.30(4.87)	4.34(18.1)	4.87(23.0)	94.5	97.5	97.2	12.2
Oxyfluorfen 120 g/ha PE *fb* propaquizafop + oxyfluorfen (PM) 43.75 +105 g/ha PoE	2.57(5.67)	5.53(30.1)	6.04(35.7)	93.6	95.8	95.6	5.0
Oxyfluorfen 150 g/ha PoE	6.86(47.1)	7.16(51.2)	9.88(98.4)	47.2	92.9	87.8	29.8
Oxadiargyl 90 g/ha PoE	7.44(55.5)	6.31(39.5)	9.71(95.0)	37.8	94.5	88.3	35.9
Clodinafop + oxyfluorfen (PM)122.5+147 g/ha PoE	2.75(6.60)	7.89(61.9)	8.30(68.5)	92.6	91.4	91.5	14.2
Propaquizafop + oxyfluorfen (PM)43.75 +105 g/ha PoE	3.38(10.7)	6.53(42.0)	7.30(52.7)	88.0	94.2	93.5	5.0
Hand weeding at 20 and 40 DATP	4.00^c(15.1)	6.73(44.9)	7.79(60.0)	83.1	93.8	92.6	4.7
Weedy check	9.41(89.2)	26.6(720)	28.2(809)	-	-	-	89.0
LSD (p=0.05)	1.85	3.78	4.04	-	-	-	-
CV%	10.8	11.1	10.0	-	-	-	-

Note: Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values in bulb yield compared with the best herbicidal treatment. However lower weed index was observed in twice hand weeding at 20 and 40 DATP followed by application of propaquizafop + oxyfluorfen (PM) 43.75 +105 g/ha PoE and oxyfluorfen 120 g/ha PE *fb* propaquizafop + oxyfluorfen (PM) 43.75 +105 g/ha PoE.

Phytotoxicity: Application of oxyfluorfen 23.5% EC 120 g/ha PE *fb* clodinafop 12.25% + oxyfluorfen 14.7% EC (PM) 122.5+147 g/ha PoE, oxadiargyl 6% EC 75 g/ha PE *fb* clodinafop 12.25% + oxyfluorfen 14.7% EC (PM) 122.5+147 g/ha PoE, oxyfluorfen 23.5% EC 150 g/ha PoE, oxadiargyl 6% EC 90 g/ha PoE showed some phytotoxicity symptoms of leaf injury and wilting on onion plants was observed visually at 7 days after herbicide application. However, the plants recover from the phytotoxicity symptoms and none of the symptoms were observed at 14 days after herbicide application.

Effect on crop: Significantly higher plant stand (476/ net plot) was observed under pendimethalin 580.5 g/ ha PPI *fb* oxyfluorfen 120 g/ha PoE but it was statistically at par with all other treatments except weedy check at harvest. Significantly taller plant (52.7 cm) was measured under weedy check at 30 DATP but it was at par with twice hand weeding at 20 and 40 DATP, pendimethalin 580.5 g/ha PPI and oxadiargyl 75 g/ha PE *fb* clodinafop + oxyfluorfen 122.5+147 g/ha PoE**.** At 60 DATP, significantly the highest plant height (84.1 cm) was measured under weedy check while non-significant difference was observed among all the herbicidal treatment with respect to recording plant height of onion in pooled results (**Table 4**).

Onion bulb yield was significantly varied due to different weed management practices and significantly higher onion bulb yield (44.3 t/ha) was achieved under pendimethalin 580.5 g/ha PPI *fb* oxyfluorfen 120 g/ha PoE as compared to weedy check, oxadiargyl 90 g/ha PoE and oxyfluorfen 150 g/ha PoE. Hembrom *et al*. (2023) also observed better control of weeds and onion bulb yield due to application of pendimethalin. Rahman *et al*. (2011) reported that hand weeding throughout the growing season controlled all weeds and resulted in higher onion bulb yield. Weedy check reported significantly the lowest (4.55 t/ha) onion bulb yield. The lowest onion bulb yield was recorded in weedy check plots owing to severe crop-weed competition resulted in low chlorophyll content and photosynthetic rate there by reducing the availability of moisture, light and nutrients to the crop thus, resulting in loss of yield (Angmo *et al*. 2018).

Economics: Data on economics of various weed management practices indicated that maximum gross return, net return and benefit cost ratio of ₹ 5,31,600/ ha, ₹ 3,37,602/ha and 2.74, respectively was achieved under pre-plant incorporation of pendimethalin 580.5 g/ha *fb* oxyfluorfen 120 g/ha applied as post-emergence which was closely followed by pre-emergence application of oxyfluorfen 120 g/ha *fb* propaquizafop + oxyfluorfen 43.75 + 105 g/ha applied at post-emergence. Among herbicidal treatment minimum gross return, net return and benefit cost ratio of ₹ 3,40,800/ha, ₹ 1,48,850/ha and 1.78, respectively was registered under oxadiargyl 90 g/ha PoE. Among all the treatment the highest cost of cultivation was observed under twice hand weeding treatment. This might be due to more

Table 4. Growth, yield and economics as influenced by weed management practices in onion (pooled data for two years)

Treatment	Plant stand (no./net plot) at harvest	Plant height (cm)		Bulb yield (t/ha)	Total cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C
		At 30 DATP	At 60 DATP					
Pendimethalin 580.5 g/ha PPI	475	49.3	70.5	38.4	191.47	460.80	269.33	2.41
Pendimethalin 580.5 g/ha PPI *fb* oxyfluorfen 120 g/ha PoE	476	47.8	70.6	44.3	194.00	531.60	337.60	2.74
Pendimethalin 580.5 g/ha PPI *fb* oxadiargyl 75 g/ha PoE	470	47.1	68.2	38.4	194.12	460.80	266.68	2.37
Oxyfluorfen 120 g/ha PE *fb* clodinafop + oxyfluorfen (PM) 122.5+147 g/ha PoE	473	48.2	72.8	38.2	196.34	458.40	262.06	2.33
Oxadiargyl 75 g/ha PE *fb* clodinafop + oxyfluorfen (PM) 122.5+147 g/ha PoE	475	45.5	70.1	38.9	196.47	466.80	270.33	2.38
Oxyfluorfen 120 g/ha PE *fb* propaquizafop + oxyfluorfen (PM) 43.75 +105 g/ha PoE	471	47.5	72.7	42.1	195.18	505.20	310.0	2.59
Oxyfluorfen 150 g/ha PoE	464	46.3	71.2	31.1	191.88	373.20	181.32	1.95
Oxadiargyl 90 g/ha PoE	464	43.5	69.0	28.4	191.95	340.80	148.85	1.78
Clodinafop + oxyfluorfen (PM)122.5+147 g/ha PoE	467	44.8	71.7	38.0	193.81	456.00	262.19	2.35
Propaquizafop + oxyfluorfen (PM)43.75 +105 g/ha PoE	474	45.9	71.2	42.1	192.65	505.20	312.55	2.62
Hand weeding at 20 and 40 DATP	471	50.2	71.0	42.2	229.25	506.40	277.15	2.21
Weedy check	162	52.7	84.1	4.55	188.98	54.60	-134.38	0.29
LSD (p=0.05)	23.6	3.96	4.53	6.71	-	-	-	-
CV%	1.2	7.8	5.8	8.3	-	-	-	-

labour was engage to remove the weeds. This results in agreement with the results of Gupta *et al*. (2020).

On the basis of two years of experimentation, it can be concluded that for obtaining healthy transplantable onion seedlings, effective management of weeds and net return, application of propaquizafop + oxyfluorfen (PM) 43.75 + 105 g/ha EPoE, oxyfluorfen 80 g/ha EPoE, pendimethalin 300 g/ha PE and twice hand weeding at 15 and 30 DAS found better. While in transplanted onion, pre-plant incorporation of pendimethalin 580.5 g/ha *fb* oxyfluorfen 120 g/ha applied as post-emergence and pre-emergence application of oxyfluorfen 120 g/ha *fb* propaquizafop + oxyfluorfen 43.75 +105 g/ha applied as post-emergence and propaquizafop + oxyfluorfen 43.75 +105 g/ha as post-emergence showed better weed control, yield and economics.

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RESEARCH ARTICLE

Weed management in *Bt.* Cotton through sequential and tank mix application of different herbicides

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ABSTRACT

A field experiment was conducted at the farm of AICRP-Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat during two consecutive *Kharif* (rainy) seasons of the year 2019 and 2020 to study the efficacy of sequential and tank mix application of different herbicides on weeds, seed cotton yield and economics of *Bt.* cotton. Significantly lower weed density and weed dry weight with higher weed control efficiency (WCE), seed cotton yield and net realization in *Bt.* cotton could be achieved by either tank mix application of pendimethalin (38.7% CS) 500 g/ha + oxyfluorfen 50 g/ha as pre-emergence (PE) *fb* tank mix application of pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha as post-emergence (PoE) or oxyfluorfen 100 g/ha as PE *fb* glufosinate ammonium 375 g/ha directed spray as PoE or IC + HW at 20, 40 and 60 DAS.

Keywords: Cotton, Economics, Herbicides, Seed cotton yield, Weed

INTRODUCTION

Weed infestation offers severe crop-weed competition in cotton and causing yield reduction to the extent of 74% (Nalini *et al.* 2015). The considerable yield losses caused due to presence of weeds in cotton have been reported by many workers. On other hand, due to shortage of labours and higher wages, farmers are severely facing problem of timely weed management in cotton. Further, frequent irrigation or heavy rains during rainy season make the farmers unable to take up timely cultural practices for weed management. Hence, it has become imperative to manage weeds by using herbicides to get higher yields. In order to manage weeds for a longer period of crop growth, herbicides need to apply on sequential basis. Sequential application of herbicides will provide consistent weed control than single application (Singh *et al.* 2004). Majority of herbicides available in the market are not broad-spectrum. Hence, we need to go for combination of herbicides or herbicide mixtures for broad-spectrum weed control. Therefore, the present study was carried out to find out the efficacy of sequential and tank mix application of different herbicides on weeds, seed cotton yield and economics of *Bt.* cotton.

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MATERIALS AND METHODS

A field experiment was carried out in loamy sand soil during two consecutive *Kharif* (rainy) season of the year 2019 and 2020 at the farm of AICRP-Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand. *Bt.* cotton variety '*GTHH 49*' was sown on June 13th, 2019 and May 31st, 2020 at a spacing of 120 x 45 cm. The crop was fertilized with recommended dose of fertilizers *i.e.* 240 kg N/ha supplied through urea only wherein, one fourth part of the nitrogen was applied as basal before sowing the crop in previously opened furrows and remaining quantity was applied in three equal splits at 30, 60 and 90 days after sowing (DAS). The experiment was laid out in a randomized block design (RBD) with four replication and ten treatments, *viz.* pendimethalin 750 g/ha (38.7% CS) as pre-plant incorporation (PPI) *fb* glufosinate ammonium 375 g/ha (15% SL) as post-emergence (PoE) directed spray, oxyfluorfen 100 g/ha (23.5 % EC) as pre-emergence (PE) *fb* glufosinate ammonium 375 g/ha PoE directed spray, pendimethalin 750 g/ha (30% EC) PE *fb* glyphosate 2000 g/ha (41% SL) PoE directed spray, pendimethalin 750 g/ha (30% EC) PE *fb* paraquat 600 g/ha PoE (24% SL) directed spray, pendimethalin 1000 g/ha (30% EC) PE *fb* pyrithiobac-sodium 62.5 g/ha (10% EC) + quizalofop-ethyl 50 g/ha (5% EC) PoE (tank mix), pendimethalin (38.7% CS) 500 g/ha + oxyfluorfen 50 g/ha PE (tank mix) *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha PoE (tank mix), pendimethalin 1000 g/ha (38.7% CS) PE *fb* IC + HW at 40 DAS, pyrithiobac-sodium 62.5 g/ha PoE + quizalofop-ethyl 50 g/ha PoE (tank mix) *fb* IC + HW at 50 DAS, IC + HW at 20, 40 and 60 DAS and weedy check. There was no any adverse condition of weather as well as pest and disease incidence on crop during the course of investigation. Pre-plant incorporation (PPI) of herbicides in respective treatments was given one day before first irrigation. Pre-emergence (PE) application of herbicides was done two days after sowing in respective treatments while post-emergence herbicides (PoE) were applied at 30 DAS. The spraying was done by using Knapsack sprayer fitted with flat-fan nozzle using 500 L of water/ha. Post-emergence herbicides mentioned in respective treatments were applied directly on weed between crop rows, avoiding crop foliage by using protective hood. Weeds associated with cotton crop in experimental area were recorded at 30, 60 DAS and at harvest from all the treatments. Observation was taken randomly from 0.25 m^2 quadrat from net plot area from each treatment and converted into m^2 area. The mean data were used for analysis. Collected weed samples at 30, 60 DAS and at harvest were allowed to sun dry and then oven dried at 65±5 °C temperature till the constant weight was obtained. The data on weed density and weed dry weight was not distributed normally hence, the data were transformed by using the square root transformation $(\sqrt{x+1})$ and then the transformed data were analyzed statistically. The visual phytotoxicity of herbicides was observed at 10 days after application of herbicides (DAHA). Phytotoxicity observations were recorded on vein clearing, necrosis, wilting, epinasty and hyponasty, *etc.* on 0-10 scale. Weed control efficiency (WCE) was calculated on the basis of formula suggested by Mani *et al.* (1973). Benefit cost ratio (BCR) value on the basis of second year data was also worked out by considering the prevailing market price on the basis of pooled seed cotton and stalk yields. Duncan's New Multiple Range (DNMRT) was employed for comparison of treatments mean and analyzed at a probability level of 5%.

RESULTS AND DISCUSSION

Effect on weeds

Altogether fourteen weed species, *viz. Commelina benghalensis, Eleusine indica (L) P.Beauv., Digitaria sanuguinalis* Scop., *Dactyloctenium aegyptium* (L.) *P.Beauv, Eragrostis major P. Beauv* and *Setaria tomentosa* (Roxb) Kunth among the monocot weeds; *Digera arvensis, Trianthema monogyna*, *Phyllanthus niruri*, *Euphorbia hirta, Oldenlanadia umbellate* and *Physalis minima* among the dicot weeds as well as *Cyperus rotundus* L. and *Cyperus iria* L. among the sedges weeds were identified in the experimental area during both the years of experimentation. All the weed control treatments caused significant reduction in total weed density and total weed dry weight production as compared to weedy check (**Table 1**).

At 30 DAS, 100% control of total weeds and thereby nil dry weight of weeds as well as 100% weed control efficiency (WCE) were recorded under application of pendimethalin (38.7% CS) 500 g/ha + oxyfluorfen 50 g/ha PE (tank mix) *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha PoE (tank mix), oxyfluorfen 100 g/ha PE *fb* glufosinate ammonium 375 g/ha PoE directed spray and IC + HW at 20, 40 and 60 DAS. It might be due to broad spectrum initial weed control provided by applied herbicide mixture (oxyfluorfen + pendimethalin) having different mode of action, high potent action of oxyfluorfen and mechanical practices, respectively under these treatments. With regards to phytotoxicity of applied herbicides on crop, none of herbicide caused any injury except oxyfluorfen which showed slight necrosis and epinasty symptoms (10 to 20%) at initial stage on cotton which was recovered in due course of time, but early cotton phytotoxicity has no significant long-term effect on crop growth and yield.

At 60 DAS, application of pyrithiobac-sodium 62.5 g/ha PoE + quizalofop-ethyl 50 g/ha PoE (tank mix) *fb* IC + HW at 50 DAS along with above three treatments reduced total weed density to the tune of 2.51, 2.66, 2.71 and 2.71/m^2, respectively. Result is in conformity with finding of Veeraputhiran and Srinivasan (2015), who recorded lesser weed density with the post-emergence application of pyrithiobac-sodium + quizalofop-ethyl in cotton. Kamble *et al.* (2017) also observed that oxyfluorfen as pre-emergence hindered the germination of weed seeds in initial stage while post-emergence application of pyrithiobac-sodium at 45 DAS might have taken care in controlling most of the later germinated broad-leaved weed species effectively.

At harvest, maximum dry weight of total weeds (21.30 g/m^2) was observed under weedy check as compared to rest of the treatments. It might be due to lack of weed management practices in weedy check lead uninterrupted growth of weeds throughout the crop season rendered the chance for better emergence, growth and development which in turn leads competition and more time to explore the nutrients from the soil by the weeds. Further, highest

WCE (92.57%) at harvest was achieved under pendimethalin (38.7% CS) 500 g/ha + oxyfluorfen 50 g/ha PE (tank mix) *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha PoE (tank mix) closely followed by oxyfluorfen 100 g/ha PE *fb* glufosinate ammonium 375 g/ha PoE directed spray and IC + HW at 20, 40 and 60 DAS. The minimum number of total weeds under said treatments could be attributed to pre-emergence application of herbicides took care of monocot and dicot weeds during initial period and later germinated weeds were controlled by application of post-emergence herbicides. Madhavi and Ramprakash (2015) also recommended herbicide mixture containing pyrithiobac sodium + quizalofop-ethyl at 100-125 g/ha for broad spectrum weed control in cotton. Singh *et al.* (2004) also concluded that glufosinate ammonium could also be used as directed spray for weed control in cotton as an alternate herbicide to glyphosate or paraquat in cotton.

Effect on crops

All the weed management practices significantly increased the plant height at harvest, number of bolls per plant, seed cotton and stalk yield (**Table 2**) over weedy check. Maximum plant height at harvest (205.44 cm), number of bolls per plant (59.50), seed cotton yield (3.24 t/ha) and stalk yield (7.79 t/ha) were reported under tank mix pre-emergence application of pendimethalin (38.7% CS) 500 g/ha + oxyfluorfen 50 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha PoE followed by pre-emergence application of oxyfluorfen 100 g/ha *fb* glufosinate ammonium 375 g/ha PoE directed spray and IC + HW at 20, 40 and 60 DAS. It might be due to fact that effective broad-spectrum weed control provided by the applied herbicide mixture, sequential herbicidal application and mechanical control of weeds at frequent interval, respectively under these treatments which helps in reducing dry weight of weeds lead to direct increase in uptake of nutrient by crop, reduced crop weed competition facilitated better translocation and accumulation of photosynthates to growing crop enabled robust growth and development of crop ultimately resulting into higher growth and yield parameters, higher seed cotton yield and stalk yield. With respect to weed index, highest yield reduction (71.01%) was observed under weedy check. These results are in agreement with the results with Jadhav and Ganesh (2022).

Economics

The economics of different treatments indicated that maximum net realization (₹ 124633/ha) and higher BCR (3.32) were attained under application of pendimethalin (38.7 % CS) 500 g/ha + oxyfluorfen 50 g/ha PE (tank mix) *fb* pyrithiobac-sodium 62.5 g/ha +

Table 1. Weed density, weed dry weight and weed control efficiency (WCE) as influenced by sequential and tank mix application of different herbicides in *Bt.* cotton (pooled over two years data)

Treatment	Total weed density (no./m^2)			Total weed dry weight (g/m^2)			Weed control efficiency (%)		
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest
Pendimethalin 750 g/ha PPI *fb* glufosinate ammonium 375 g/ha PoE	3.42[bc] (10.78)	4.07[d] (15.60)	6.11[e] (36.33)	4.73[c] (21.54)	6.91[d] (46.99)	10.91[d] (118.19)	81.76	83.30	73.97
Oxyfluorfen 100 g/ha PE *fb* glufosinate ammonium 375 g/ha PoE	1.00[d] (0.00)	2.71[f] (6.35)	4.15[f] (16.43)	1.00[d] (0.00)	3.32[f] (10.15)	6.44[e] (40.77)	100.00	96.39	91.02
Pendimethalin 750 g/ha PE *fb* glyphosate 2000 g/ha PoE	3.61[bc] (12.13)	4.91[c] (23.23)	6.60[cd] (42.68)	5.10[bc] (25.26)	8.14[c] (65.63)	11.95[c] (142.25)	78.61	76.68	68.67
Pendimethalin 750 g/ha PE *fb* paraquat 600 g/ha PoE	3.75[b] (13.15)	6.41[b] (40.10)	8.07[b] (64.23)	5.27[b] (26.88)	11.10[b] (122.48)	15.08[b] (227.11)	77.24	56.48	49.98
Pendimethalin 1000 g/ha PE *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha PoE (tank mix)	3.38[c] (10.60)	4.32[d] (17.68)	6.59[cd] (42.63)	4.79[bc] (22.26)	7.01[d] (48.33)	12.13[c] (146.50)	81.15	82.83	67.73
Pendimethalin 500 g/ha + oxyfluorfen 50 g/ha PE (tank mix) *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha PoE (tank mix)	1.00[d] (0.00)	2.66[f] (6.13)	3.96[f] (14.73)	1.00[d] (0.00)	3.27[f] (9.76)	5.88[e] (33.72)	100.00	96.53	92.57
Pendimethalin 1000 g/ha PE *fb* IC + HW at 40 DAS	3.51[bc] (11.43)	3.69[e] (12.68)	6.98[c] (47.75)	4.95[bc] (23.62)	4.88[e] (22.97)	12.64[c] (158.87)	80.00	91.84	65.01
Pyrithiobac-sodium 62.5 g/ha PoE + quizalofop-ethyl 50 g/ha PoE (tank mix) *fb* IC + HW at 50 DAS	7.55[a] (56.10)	2.51[f] (5.43)	6.31[de] (38.88)	10.64[a] (112.38)	2.84[g] (7.13)	11.07[d] (121.72)	4.86	97.47	73.19
IC + HW at 20, 40 and 60 DAS	1.00[d] (0.00)	2.71[f] (6.35)	3.88[f] (14.10)	1.00[d] (0.00)	3.27[f] (9.83)	6.28[e] (38.78)	100.00	96.51	91.46
Weedy check	7.72[a] (58.93)	9.48[a] (88.98)	10.54[a] (110.40)	10.88[a] (118.12)	16.80[a] (281.43)	21.30[a] (454.01)	-	-	-
LSD (p=0.05)	0.38	0.28	0.36	0.45	0.41	0.67	-	-	-

Note: All figures are subjected to transformed values to square root ($\sqrt{x+1}$). Figures in parentheses indicate original values. Mean followed by common letter (s) in column are not significant by DNMRT at 5 % level of significance

Table 2. Weed index, yield and economics of *Bt.* cotton as influenced by sequential and tank mix application of different herbicides (pooled over two years data)

Treatment	Weed index (%)	Plant height at harvest (cm)	Bolls/ plant	Seed cotton yield (t/ha)	Stalk yield (kg/ha)	Net realization (₹ /ha)	Benefit cost ratio
Pendimethalin 750 g/ha PPI *fb* glufosinate ammonium 375 g/ha PoE	18.25	186.82[bc]	48.28[b]	2.65[b]	6.27[b]	94060	2.82
Oxyfluorfen 100 g/ha PE *fb* glufosinate ammonium 375 g/ha PoE	6.51	199.58[ab]	56.60[a]	3.03[a]	7.24[a]	115574	3.26
Pendimethalin 750 g/ha PE *fb* glyphosate 2000 g/ha PoE	19.52	181.94[cd]	47.78[b]	2.61[b]	6.12[b]	92140	2.79
Pendimethalin 750 g/ha PE *fb* paraquat 600 g/ha PoE	27.72	170.32[de]	43.55[c]	2.34[b]	5.33[c]	78269	2.55
Pendimethalin 1000 g/ha PE *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha PoE (tank mix)	21.52	178.04[cd]	47.18[bc]	2.55[b]	5.94[bc]	86395	2.61
Pendimethalin 500 g/ha + oxyfluorfen 50 g/ha PE (tank mix) *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha PoE (tank mix)	-	205.44[a]	59.50[a]	3.24[a]	7.79[a]	124633	3.32
Pendimethalin 1000 g/ha PE *fb* IC + HW at 40 DAS	24.55	175.88[cde]	46.15[bc]	2.45[b]	5..67[bc]	81184	2.52
Pyrithiobac-sodium 62.5 g/ha PoE + quizalofop-ethyl 50 g/ha PoE (tank mix) *fb* IC + HW at 50 DAS	39.69	163.77[e]	36.78[d]	1.96[c]	4.40[d]	53109	1.97
IC + HW at 20, 40 and 60 DAS	8.33	196.85[ab]	55.98[a]	2.97[a]	7.07[a]	106210	2.85
Weedy check	71.01	144.99[f]	23.98[e]	0.94[d]	2.00[e]	5279	1.11
LSD (p=0.05)	-	11.38	3.72	0.30	0.70	-	-

Note: All figures are subjected to transformed values to square root ($\sqrt{x+1}$). Mean followed by common letter (s) in column are not significant by DNMRT at 5 % level of significance

quizalofop-ethyl 50 g/ha PoE (tank mix) followed by application of oxyfluorfen 100 g/ha PE *fb* glufosinate ammonium 375 g/ha PoE directed spray and IC + HW at 20, 40 and 60 DAS, respectively (**Table 2**). The higher seed cotton yield recorded under above said treatments might be responsible for net realization. These results are in accordance with the results of Veeraputhiran and Srinivasan (2015), Kamble *et al.* (2017) and Jadhav and Ganesh (2022).

It can be concluded that higher seed cotton yield, net return and effective weed management in *Bt.* cotton could be achieved by either tank mix application of pendimethalin (38.7 % CS) 500 g/ha + oxyfluorfen 50 g/ha as PE *fb* tank mix application of pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha as PoE or sequential application of oxyfluorfen 100 g/ha as PE *fb* glufosinate ammonium 375 g/ha directed spray as PoE or interculturing and hand weeding at 20, 40 and 60 DAS.

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RESEARCH ARTICLE

Explaining distributional patterns of *Trianthema portulacastrum* and *Ageratum conyzoides* in India under future climatic scenarios using Ensemble modelling approach

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ABSTRACT

Weeds are recognized as the most aggressive, troublesome, and competitive elements within croplands. Climate change may affect the geographical distribution of existing weeds or the invasion of weeds in new areas. Therefore, in the current study, modelling was carried out to explore and predict the invasion potential of *Trianthema portulacastrum* and *Ageratum conyzoides* in India under current as well as future climatic conditions. Future climatic scenarios under Representative Concentration Pathways (RCPs) 4.5 and 8.5 for the years 2050 and 2070 were considered and modelling was performed using regression techniques and machine learning approaches with Ensemble technique. Mutually least correlated eight bioclimatic variables along with soil and elevation data were used for the modelling over 375 and 379 occurrence locations of the *T. portulacastrum* and *A. conyzoides*, respectively. True Skill Statistic (TSS) was used to evaluate the models' predictive performance, while AUC of the ROC and Kappa were used to crosscheck their performance. Results revealed that Ensemble model outperformed the individual models for both the species with higher AUC, TSS and Kappa values. Bioclimatic variables such as temperature seasonality, annual mean temperature, and minimum temperature of the coldest month were found to govern the potential distribution of both the species. Results of potential distribution were obtained in four climate suitability classes: not suitable (0-0.2), low (0.2-0.4), moderately (0.4-0.6), and highly suitable (>0.6). Modelling suggests the expansion of suitable ranges of *T. portulacastrum* in India under future climatic scenarios, whilst *A. conyzoides* are expected to predominantly contract in the future.

Keywords: Bioclimatic variables, Ensemble modelling, Machine learning, Potential distribution, Species distribution modelling

INTRODUCTION

Weeds are regarded as the most damaging biotic constraint to agricultural production, in addition to threatening agro-biodiversity and natural water bodies. Weeds compete for primary resources such as light, water, nutrients and space that limit the agricultural production and cause huge yield and economic losses. It is estimated that weeds reduce crop yields by 31.5% (22.7% in winter and 36.5% in summer and rainy seasons) in India (Bhan *et al*. 1999). It is estimated to cause an economic loss of about USD 11 billion in 10 major field crops in India due to weeds (Gharde *et al*. 2018, 2019).

The introduction of alien invasive species poses a serious threat to native biodiversity, ecosystem integrity, and agricultural productivity, resulting in significant economic consequences (Rai and Singh 2020). Invasive species disrupt trophic balance and reduce species resilience. Furthermore, global climate change increases the risk of alien and invasive plant species while also expanding their range. Previous research has found that many alien and invasive species have characteristics that increase invasion success and allow them to easily adapt to climate change (Priyanka and Joshi 2013; Banerjee *et al*. 2017).

Climate change may be the driver for global range expansions (migration or introduction into new areas), and changes in life cycles of species. Weed migration may result in a difference in the structure and composition of weed communities in natural and managed ecosystems (Ramesh *et al*. 2017). Identifying possible habitats integrating changing climate scenarios is an effective strategy for reducing the spread of invasive plant species. Species distribution models (SDMs) are the most commonly utilised tool for investigating the effects of climate change on distributions (Gharde *et al*. 2023). SDMs anticipate the distributions of given species based on

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abiotic factors such as environmental data, making it primarily a tool for predicting the fate of a species in the future in terms of ecology and conservation. These models also aid in understanding existing and potential relationships between species, organisms, environmental conditions, and area richness (Elith *et al*. 2006). SDMs are an evolved version of the predictive habitat distribution models (Guisan and Zimmermann 2000).

Among alien invasive weeds (AIWs), species such as *Trianthema portulacastrum* and *Ageratum conyzoides* have posed serious threats to biodiversity in the country. Both weeds are native to Africa and are considered troublesome weeds in cultivated crops. *T. portulacastrum* also known as horse purslane, is an annual broadleaf weed belonging to the Aizoaceae family and is a widely distributed weed in mustard, corn, pigeon pea, soybean, tomato, potato, onion, cotton, sugarcane, pearl millet, sorghum, maize, direct-seeded rice, summer and rainy season pulses, oilseed crops, fodder crops, vegetables and horticultural crops in India. This weed is said to be a strong competitor, reducing mungbean yield by 50-60% when left untreated (Kaur *et al*. 2017; Aggarwal *et al*. 2017). It is also responsible for significant losses in maize, soybean, and peanut yield. Its extract has an allelopathic effect on soybean seed germination, seedling vigour, and productivity.

Ageratum conyzoides, called Billygoat weed, is an annual broad-leaf weed belonging to the family Asteraceae. It reduces yields in major staple crops such as wheat, corn and rice in India (Kohli *et al*. 2006; Batish *et al*. 2006; Kaur *et al*. 2012). It also infiltrates rangeland areas, where it outcompetes native grasses, resulting in a lack of fodder. Its growth strategies, which include rapid growth rates, short life cycles, increased reproductive potential, high competitive abilities, and allelopathy, make it a successful invader of native habitat (Kohli *et al*. 2006; Batish *et al*. 2006; Singh *et al*. 2012).

Considering the negative impact of these two weeds on the performance of different crops in terms of yield and economics, the proposed work aims to study the current geographical distribution of *T. portulacastrum* and *A. conyzoides* and to predict the future expansion/contraction of the species under RCP 4.5 and 8.5 for the years 2050 and 2070 using Ensemble -modelling approach. The study will be helpful to the researchers in identifying the potential areas of invasion for the species and accordingly, plan the strategies for the prevention of these species in newer areas.

MATERIALS AND METHODS

Data collection

The study was conducted during the year 2023 at ICAR-Directorate of Weed Research, Jabalpur. For the study, occurrence data for *T. portulacastrum* and *A. conyzoides* were obtained from various sources, including India Biodiversity Portal (https://indiabiodiversity.org/); Global Biodiversity Information Facility GBIF (https://www.gbif.org/); Centre for Agriculture and Bioscience International CABI (https://www.cabi.org); Flora of Peninsular India, Herbarium JCB, Centre for Ecological Sciences, Indian Institute of Sciences, Bengaluru (http://flora-peninsula-indica.ces.iisc.ac.in/) and https://www.inaturalist.org/. Occurrence records acquired from Annual Reports of the All India Coordinated Research Project on Weed Management and ICAR-Directorate of Weed Research (DWR) (2010-2022), Weed Atlas, Vol. I and II published in 2008 by the ICAR-DWR were also included. However, over-lapping occurrence points were removed before analysing the data. Altogether 375 occurrence points of *T. portulacastrum* and 379 occurrence points of *A. conyzoides* were considered for the study.

Climatic variables

Climatic variables (often called bioclimatic data primarily used for ecological applications) namely bio1 through bio19 with a resolution of 30 arc seconds were downloaded from the website www.worldclim.org for current and two future climate periods, e.g. 2050 (2041-2060 average) and 2070 (2061-2080 average) under Representative Concentration Pathways (RCP) 4.5 and 8.5. As these files were in tiff format, QGIS-v3.22.7 software was used to convert them to ASCII (American Standard Code for Information Interchange) format. Elevation data from the Shuttle Radar Topography Mission (SRTM) and soil layers from www.worldclim.org and OpenLandMap.org, respectively, were also considered for the study that influenced the distribution of species. The soil layer's resolution was set to 30 arc seconds and converted to ASCII format before the analysis.

RCP 4.5 denotes the average/moderate GHG emission pathway, whereas RCP 8.5 denotes the greatest GHG concentration pathway (IPCC 2014; Thapa *et al*. 2018). The RCP 4.5 model predicts a steady increase in radiative forcing with projected global mean surface temperatures ranging from 1.4°C to 1.8°C, whereas the RCP 8.5 model assumes the greatest increase in radiative forcing with projected global mean surface temperatures ranging from 2.0°C to 3.7°C. Future climate data under RCP 4.5 and 8.5 for the years 2050 and 2070 under the model cccma_canes2 was used for modelling.

Data pre-processing

Duplicate records of the occurrence data of *T. portulacastrum* and *A. conyzoides* were omitted using the conditional formatting function available in MS Excel and finally, 375 occurrence points of *T. portulacastrum* and 379 points of *A. conyzoides* were retained for model building and validation for the species distribution modelling. Predictor variables from bio1 through bio19 were tested for multicollinearity using correlogram. Out of 19 bioclimatic variables, strongly associated bioclimatic variables with Pearson correlation coefficient values >0.8 and <-0.8 were eliminated from the analysis, leaving eight variables with the least mutual association across the study area. With this criteria, 8 bioclimatic variables, as well as the elevation layer and soil layer, were retained for model development and validation. Thus, selected climatic variables are bio 1 (Annual Mean Temperature), bio 4 (Temperature Seasonality (standard deviation *100)), bio 5 (Maximum Temperature of Warmest Month), bio 6 (Minimum Temperature of Coldest Month), bio 9 (Mean Temperature of Driest Quarter), bio 10 (Mean Temperature of Warmest Quarter), bio 12 (Annual Precipitation), bio 14 (Precipitation of Driest Month).

Raster layers of environmental variables were trimmed to get the study region's (India) spatial range (latitudes 8°42 N and 37°6' N, and longitudes 68°7' E and 97°25' E, with a total area of 3,287,263 km^2). Maps in **Figure 1 and 2** depict the occurrence points of *T. portulacastrum* and *A. conyzoides* in the study region of India, respectively.

Model fitting, calibration and validation

The geographical distribution of *T. portulacastrum* and *A. conyzoides* was obtained with the BIOMOD2 package available in R. Unlike the single model technique, BIOMOD2 incorporates an Ensemble modelling algorithm and is thought to produce higher accuracy. Ensemble modelling is a process where multiple diverse models are generated to predict an outcome, by using many different modelling algorithms. The Ensemble model then integrates the prediction of each base model and results in one final prediction. The purpose of using Ensemble models is to minimize the generalization error of the prediction.

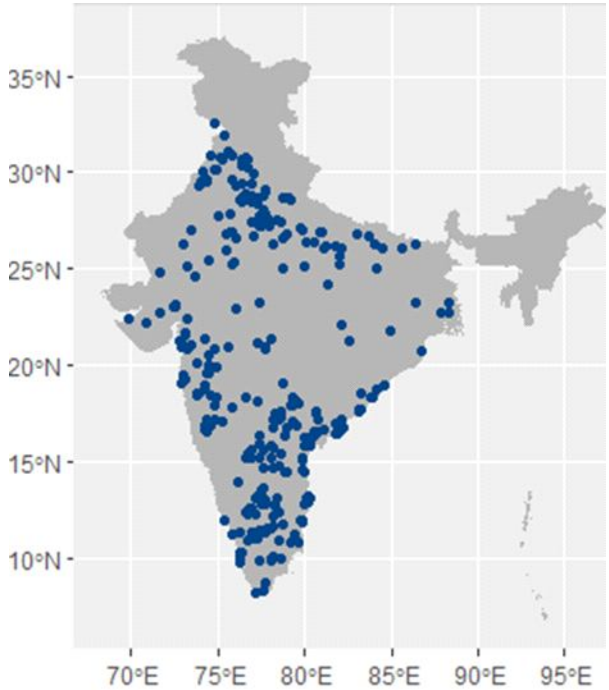


Figure 1. Map depicting the occurrence points of *T. portulacastrum* in the study region

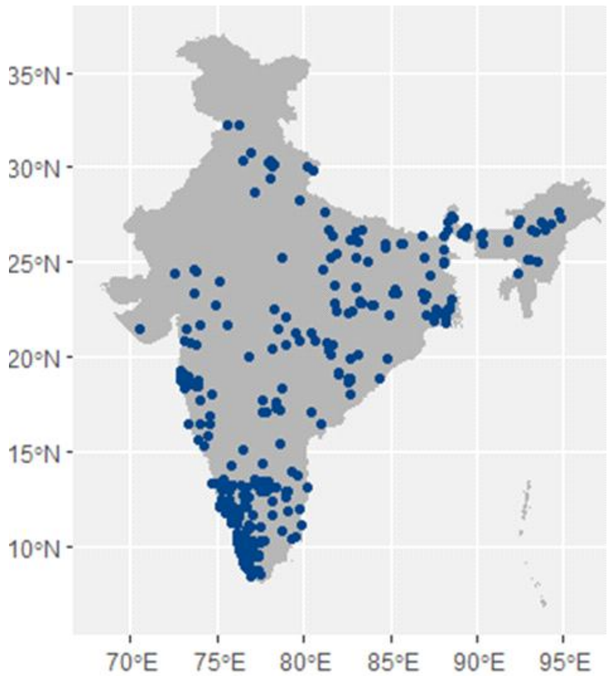


Figure 2. Map depicting the occurrence points of *A. conyzoides* in the study region

For generating the Ensemble model, five algorithms from the BIOMOD2 package in R were used. These include two regression approaches (Generalised Linear Model (GLM), Multivariate Adaptive Regression Splines (MARS)) and three machine learning methods (Maximum Entropy (MaxEnt); Artificial Neural Network (ANN) and Random Forest (RF)).

Similar to species presence points, absence points are regarded as valuable data in SDM. SDM algorithms and model assessment procedures consider missing data to be an essential factor. Because there were no actual absence points rather pseudo-absence points were constructed within the model using a random technique. Based on the BIOMOD2 package's guidance, three times as many presence points were generated as pseudo absence points for modelling the weeds *T. portulacastrum* and *A. conyzoides*. The data was divided into two sets: 75% of the data was utilized for the calibration procedure, and the remaining 25% was used as testing data set. A ten-fold cross-validation strategy was used to lower the uncertainty in the response curves and occurrence predictions. The method involves dividing the occurrence data into 10 equal-size groups, or "folds," at random. Models are then created by excluding each fold in turn, with the left-out fold being used for model validation. It uses all of the data for validation as a result. The predicted probability layers were then averaged to get the final model output.

Model evaluation

There are different ways for assessing the model's predicted performance. For evaluation, many researchers employed Area under Receiver Operating Characteristic (ROC) curve (AUC) and True Skill Statistic (TSS). Both methods can be used alone, but it is best to employ them all for cross-comparisons. Here, TSS was used to evaluate model predictive performance, while AUC of the ROC and Kappa were utilised to crosscheck model predictive performance. Models with AUC > 0.7, TSS > 0.4 and Kappa > 0.4 were used for building the Ensemble model.

The area under ROC curve (AUC) indicates the degree or measure of separability, whereas ROC is a probability curve between the True positive rate (TPR) and False positive rate (FPR). It takes values from 0 to 1, where a value of 0 indicates a perfectly inaccurate test and a value of 1 reflects a perfectly accurate test. In general, an AUC of 0.5 suggests no discrimination, 0.7 to 0.8 is considered acceptable, 0.8 to 0.9 is considered excellent, and more than 0.9 is considered outstanding.

True Skill Statistic (TSS) describes the ability of a model to correctly classify presence and background data. TSS > 0.8 excellent; 0.6 <TSS < 0.8 good; 0.4 < TSS < 0.6 fair; 0.2 < TSS < 0.4 poor; and TSS < 0.2 no predictive ability.

The Kappa statistic is frequently used to test interrater reliability. The importance of interrater reliability lies in the fact that it represents the extent to which the data collected in the study are correct representations of the variables measured. It ranges from -1 to 1. Values d" 0 as indicating no agreement and 0 - 0.20 as none to slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement.

Using TSS scores as a cut-off value, maps depicting the probabilities of suitable and unsuitable areas of current and future distribution of *T. portulacastrum* and *A. conyzoides* was obtained and prepared in four classes of climate suitability i.e., not suitable (0-0.2), low (0.2-0.4), moderately (0.4-0.6) and highly suitable (>0.6) categories.

Apart from this, the permutation approach was used to analyse the relative influence of each climate variable on the distribution of selected plant species. To demonstrate the relationship between the probabilities of occurrence for a species with varying values of environmental variables, response curves were also created. One environmental variable is simulated for each plot, with the remaining environmental variables kept constant at their mean.

The biomod range size function in the BIOMOD2 package was used to visualise and measure the range change of the target plant species under future climatic circumstances. The function offers a summary statistic on species range change. "Percentage loss" (*i.e.*, the percentage of currently suitable areas predicted to be lost, calculated as [loss/ (loss + stable)]; "percentage gain" (*i.e.*, the percentage of new habitats predicted to be suitable when compared to the species' current distribution size, calculated as [gain/ (gain + stable)]; and "range change," i.e., the overall output of predictions, calculated as (percentage gain-percentage loss).

RESULTS AND DISCUSSION

Variable selection

In **Figure 3**, the correlations for all pairs of variables are represented by the correlogram. Positive correlations are shown in blue, while negative correlations are shown in red. The intensity of the colour is proportional to the correlation coefficient, therefore, the darker the circle, the stronger the correlation (*i.e.*, closer to -1 or 1). The correlation coefficients and related hues are shown in the colour legend on the right side of the correlogram. Strongly connected bioclimatic variables with Pearson correlation coefficient values >0.8 and <-0.8 were removed from the analysis, leaving eight variables with the least mutual association across the study area.

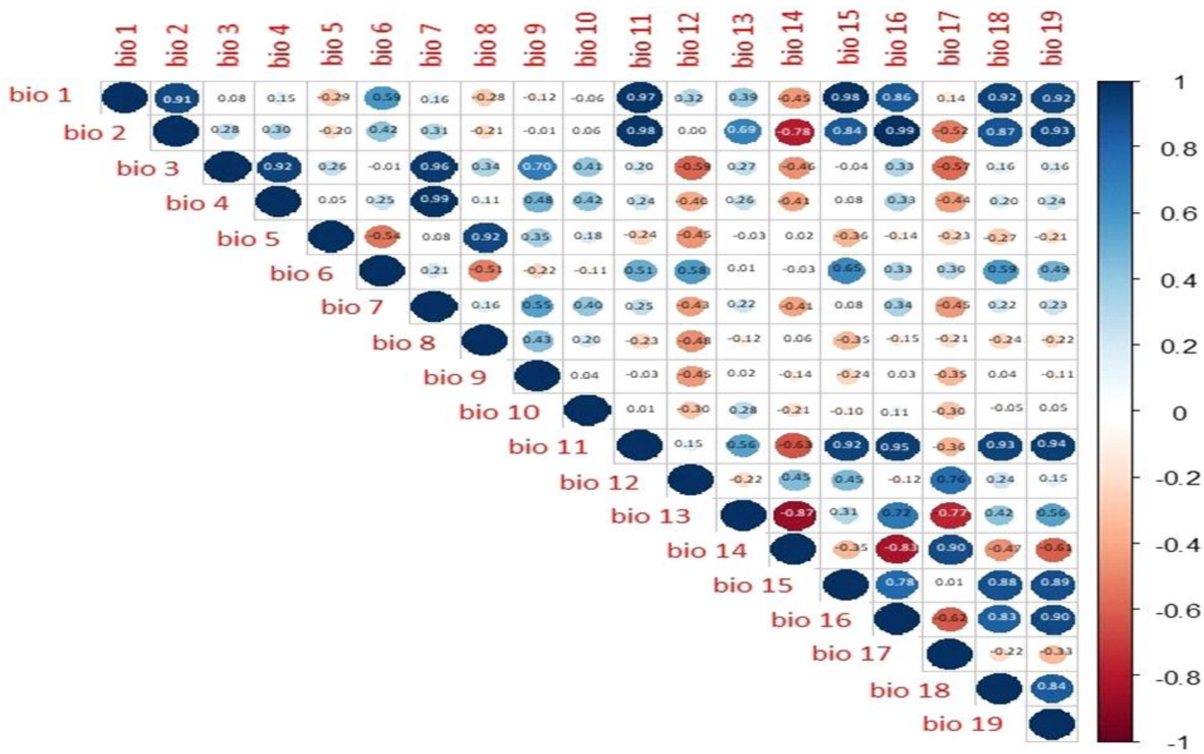


Figure 3. Correlogram- Multicollinearity among environment predictors

The bioclimatic variables that were retained are:

- bio 1 (Annual Mean Temperature)
- bio 4 (Temperature Seasonality (standard deviation *100))
- bio 5 (Max Temperature of Warmest Month)
- bio 6 (Min Temperature of Coldest Month)
- bio 9 (Mean Temperature of Driest Quarter)
- bio 10 (Mean Temperature of Warmest Quarter)
- bio 12 (Annual Precipitation)
- bio 14 (Precipitation of Driest Month)

Along with eight bioclimatic variables, elevation layer and soil layer were also used for model building and validation.

Model building and validation for *Trianthema portulacastrum*

Performance score of all models along with Ensemble approach are given in **Table 1** for comparison. From **Table 1,** it is clear that the scores of individual model based on AUC value, ranges from 0.755 (ANN) to 0.849 (RF), whereas TSS value, ranges from 0.403 (RF) to 0.551 (MARS), and KAPPA value from 0.421 (MaxEnt) to 0.510 (GLM). The best performing model based on AUC is RF, whereas the TSS score is high in case of MARS, and the high KAPPA statistic in case of GLM. All the single models outperformed the random models. However, the Ensemble model gave higher AUC value (0.872), TSS value (0.606) and Kappa statistic (0.547) as compared to other models.

Table 1. Performance score of individual models along with Ensemble model for *Trianthema portulacastrum*

MODEL	AUC	TSS	KAPPA statistic
MaxEnt	0.818	0.468	0.421
RF	0.849	0.403	0.439
ANN	0.755	0.496	0.422
MARS	0.846	0.551	0.475
GLM	0.832	0.537	0.510
ENSEMBLE	0.872	0.606	0.547

Figure 4 shows the response curves of environmental predictors affecting the prediction of Ensemble model of *Trianthema portulacastrum*. As shown in **Table 2**, the three most important variables influencing the model are bio 4 (temperature seasonality), bio 12 (annual precipitation), and bio 6 (minimum temperature of the coldest month). Therefore, they are discussed here. It is clear from the curve that for the growth of *T. portulacastrum*, it needs a temperature of at least 5 °C. There is a higher chance of weed occurrence when temperatures seasonality is above 450. Weed occurrence is quite probable in areas with annual precipitation of approximately 950 mm.

Current distribution pattern of *T. portulacastrum*

As shown in **Figure. 5**, major parts of Punjab, Haryana, and the north-western part of Uttar Pradesh are classified as highly suitable in the north zone; states such as Tamil Nadu, Karnataka, Telangana, and

Table 2. Performance of predictor variables used in species distribution modelling of *Trianthema portulacastrum*

MODEL	bio 1	bio 4	bio 5	bio 6	bio 9	bio 10	bio 12	bio 14	Elevation	Soil
MaxEnt	**0.4976**	0.1930	**0.3113**	0.0501	0.1293	0.1377	**0.3502**	0.0647	0.1854	0.0385
RF	0.0493	**0.1288**	0.0596	**0.0787**	0.0622	0.0373	**0.1081**	0.0217	0.0551	0.0102
ANN	0.2209	0.0680	0.1063	0.2254	0.0436	0.1402	**0.7612**	**0.2387**	**0.3723**	0.2089
MARS	0.0000	**0.5015**	0.0659	**0.7478**	0.1686	0.0000	**0.3750**	0.0558	0.0517	0.0000
GLM	0.2732	**0.4995**	0.0000	**0.8409**	0.0000	**0.5926**	0.1539	0.0784	0.0000	0.0140
ENSEM-BLE	0.0799	**0.2718**	0.0542	**0.3861**	0.0334	0.0438	**0.2932**	0.0450	0.0312	0.0249

The most important variables in each model are highlighted in bold

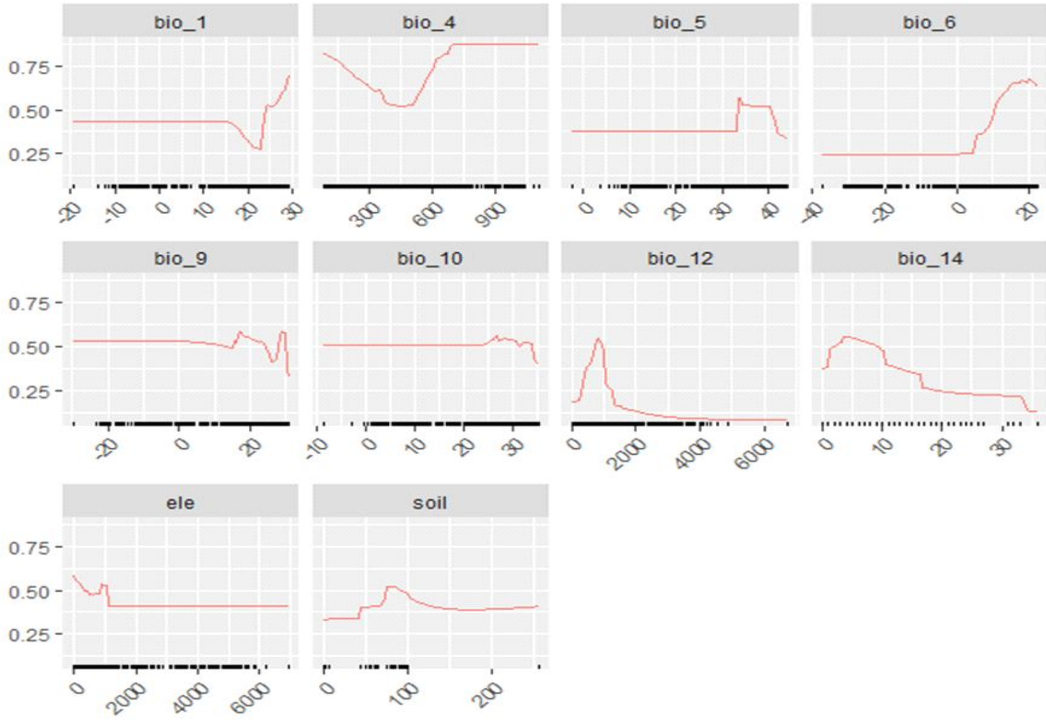


Figure 4. Response curves of environmental predictors affecting the prediction of Ensemble model for *Trianthema portulacastrum*

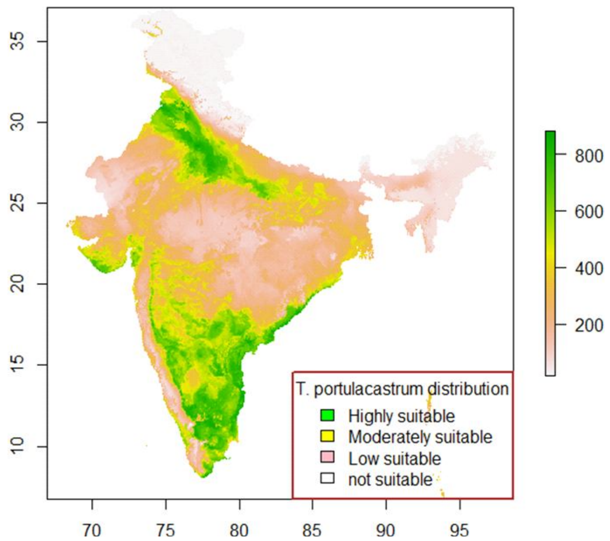
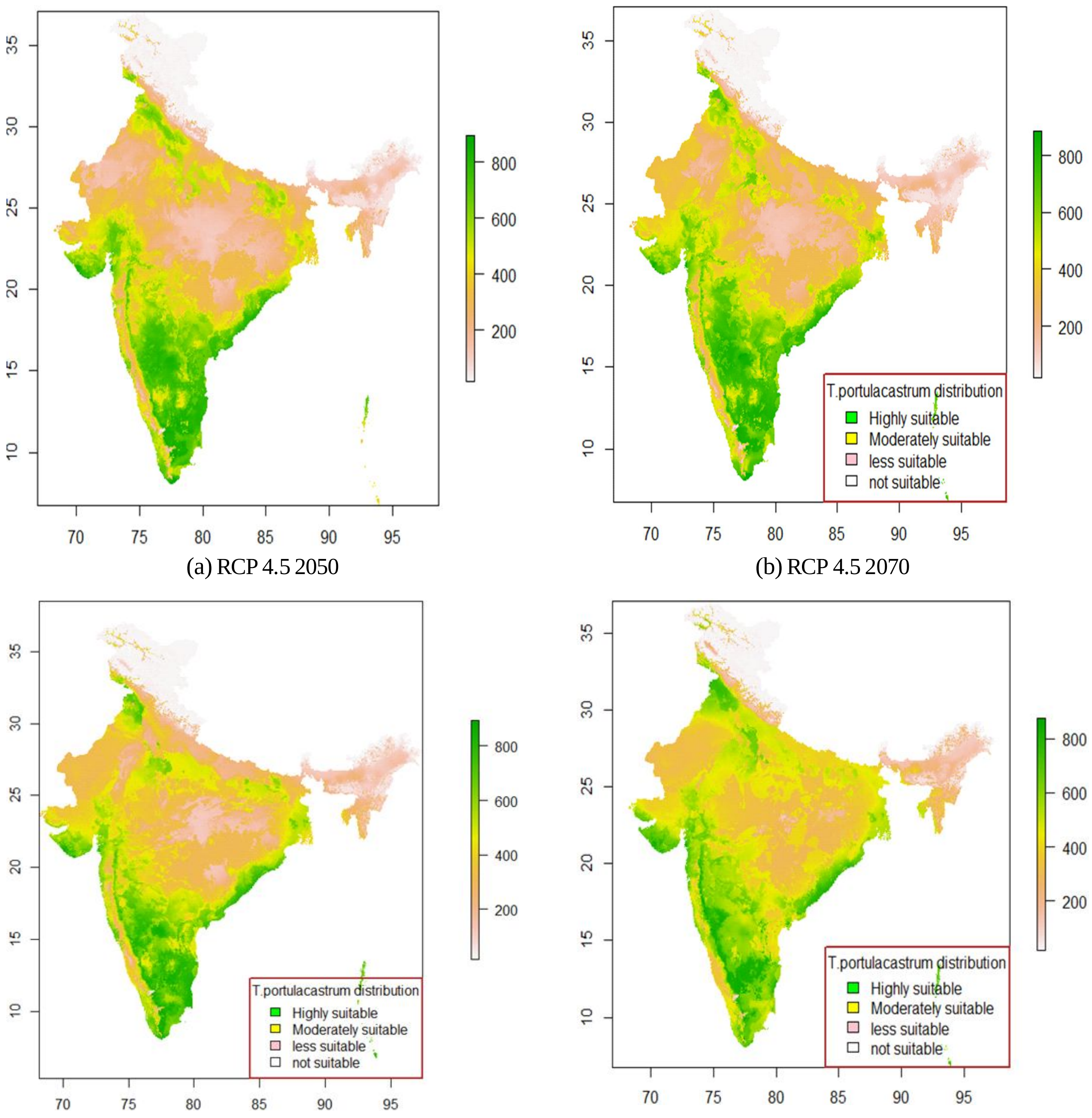


Figure 5. Predicted distribution of *Trianthema portulacastrum* in India under current climate conditions based on Ensemble model

Andhra Pradesh are classified as highly suitable in south zone; and, some parts of western Maharashtra and coastal areas of Gujarat are classified as highly suitable in the western zone of India for the growth of *T. portulacastrum.*

Future distribution pattern of *T. portulacastrum*

From **Figure 6** and **Table 3**, it can be found that *T. portulacastrum* will undergo significant range changes under all the future climatic scenarios with a gain in habitat suitability. Mandal *et al.* (2017) also found that *T portulacastrum* had high acclimatization capacity and produced more growth under elevated temperature up to ambient+4°C. In the present study, it is observed that invasion hotspots for *T. portulacastrum* will be shifted towards the south and east of the country including a few western parts like Gujarat, in all four future climatic scenarios.



(a) RCP 4.5 2050 (b) RCP 4.5 2070

(c) RCP 8.5 2050 (d) RCP 8.5 2070

Figure 6. Predicted suitable regions for *Trianthema portulacastrum* in India under future climatic scenarios based on Ensemble model

Table 3. Summary of the range change statistics for the *Trianthema portulacastrum* under different climate change scenarios compared to current climatic conditions

Scenario	Loss %	Gain %	Change %
RCP 4.5 2050	18.90	53.70	34.80
RCP 4.5 2070	18.32	61.22	42.90
RCP 8.5 2050	22.50	50.88	28.38
RCP 8.5 2070	20.05	74.03	53.97

Model building and validation for *A. conyzoides*

Performance score of all models along with Ensemble approach are given in **Table 4** for comparison. It is clear that the scores of individual models based on AUC value ranges from 0.774 (ANN) to 0.837 (MARS), whereas TSS value ranges from 0.441 (MaxEnt) to 0.491 (GLM) and Kappa value from 0.445 (MaxEnt) to 0.512 (RF). The best-performing model based on AUC is MARS, whereas the TSS score is high in case of GLM, and Kappa statistic in the case of RF. All of the single models outperformed the

Table 4. Performance score of individual model along with Ensemble model for *Ageratum conyzoides*

MODEL	AUC	TSS	Kappa statistic
MaxEnt	0.809	0.441	0.445
RF	0.832	0.462	**0.512**
ANN	0.774	0.462	0.449
MARS	**0.837**	0.483	0.510
GLM	0.825	**0.491**	0.479
ENSEMBLE MODEL	**0.840**	**0.522**	**0.525**

random models. However, Ensemble model gave higher AUC value (0.840), TSS (0.522) and Kappa statistic (0.525) as compared to other models.

Table 5 displays the importance of predictor variables used in *A. conyzoides* distribution modelling for each model. The model is predominantly influenced by predictor variables such as bio 12 (Annual Precipitation), bio 4 (Temperature Seasonality), and bio 6 (Minimum Temperature of the Coldest Month).

Figure 7 revealed that the *A. conyzoides* is not a cold region weed, as its occurrence probability is 0 below 0°C. Arora (1999) found that places with temperatures ranging from 20–25 °C are best suited to its growth and development but it also survives well at 15–30°C. This explains its occurrence at higher altitudes (i.e., temperate climates) as well as on the plains (*i.e.*, tropical climates) (Kosaka *et al.* 2010). Response curves show that as temperature seasonality increases, its occurrence probability decreases, indicating it is not tolerant to extreme temperature variability. It indicates that places with less difference between highest and lowest temperature are favourable for this weed. Annual precipitation of 2000–3700 mm has a high likelihood of weed occurrence.

Current distribution pattern of *A. conyzoides*

According to **Figure 8**, the southern part of Uttarakhand is classified as a moderately suitable area

Table 5. Performance of predictor variables used in species distribution modelling of *Ageratum conyzoides*

MODEL	bio 1	bio 4	bio 5	bio 6	bio 9	bio 10	bio 12	bio 14	Elevation	Soil
MaxEnt	0.0524	**0.3141**	0.0184	**0.1279**	0	0	**0.1638**	0.0038	0.0069	0.0097
RF	0.0308	**0.1345**	**0.0570**	0.0465	0.0368	0.0407	**0.1123**	0.0167	0.0307	0.0094
ANN	0.0890	**0.5691**	**0.0934**	0.0424	0.0645	0.0485	**0.3875**	0.0207	0.0854	0.0660
MARS	0.0508	**0.2687**	**0.4432**	**0.9212**	0.0518	0	0.0813	0	0.2249	0
GLM	0	**0.3506**	0	0	**0.2723**	0	**0.1749**	0.0084	0.0544	0.0508
ENSEMBLE	0.0163	**0.1283**	0.0543	**0.1093**	0.0241	0.0050	**0.1632**	0.0034	0.0276	0.0138

The most important variables in each model are highlighted in bold.

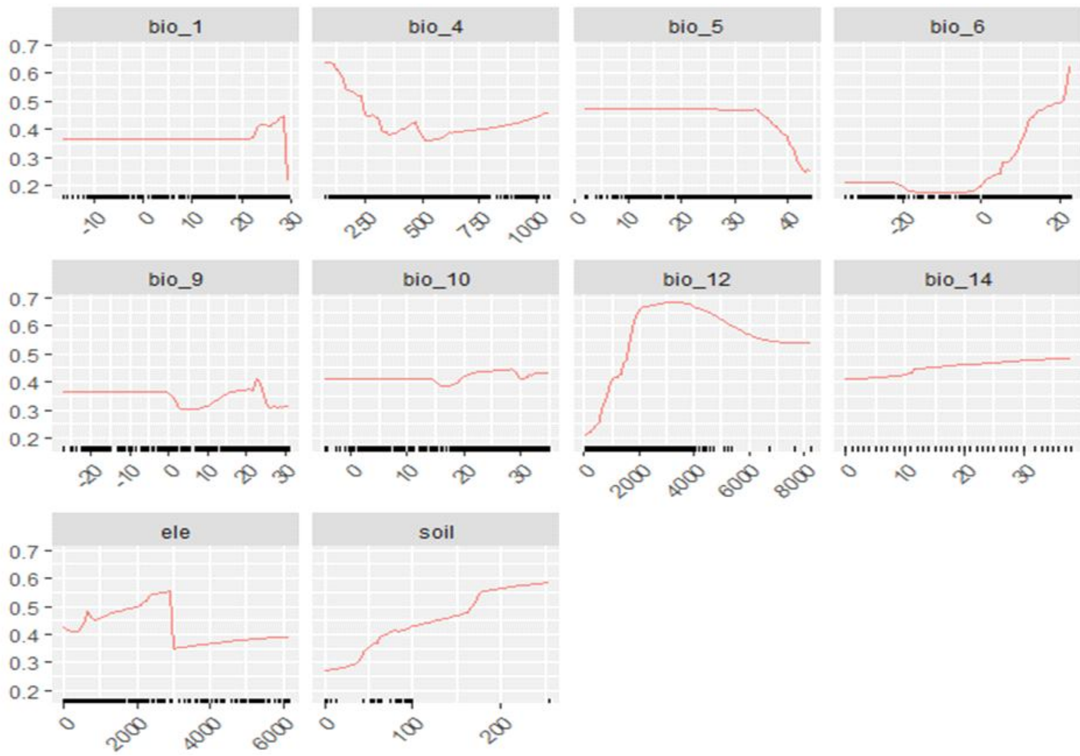


Figure 7. Response curves of environmental predictors affecting the prediction of Ensemble model for *Ageratum conyzoides*

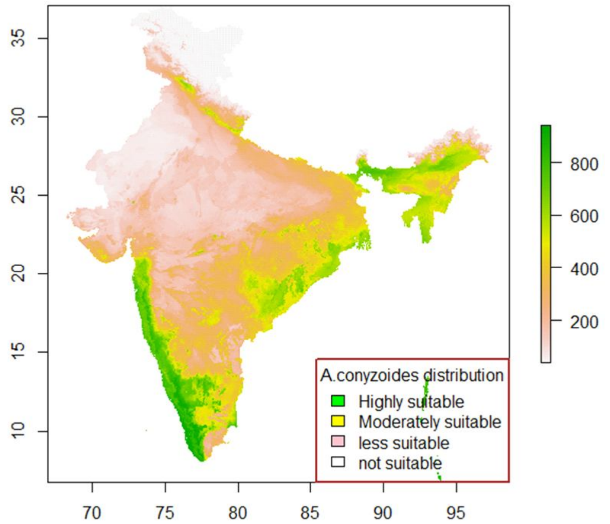


Figure 8. Predicted suitable regions of *Ageratum conyzoides* in India under current climate conditions based on Ensemble model

in the north zone; in the south zone, Kerala, coastal Karnataka, and the northern portion of Andhra Pradesh are classified as moderately suitable, and in the eastern zone of India, the coastal regions of Odisha and West Bengal are classified as highly suitable for the growth of *A. conyzoides.* In India's north-eastern region, all the states, i.e., Assam, Sikkim, Nagaland, Meghalaya, Manipur, Mizoram, and Tripura, come under the moderately to a highly suitable category, except Arunachal Pradesh, which comes under the less suitable category.

Future distribution pattern of *A. conyzoides*

From **Figure 9** and **Table 6**, it can be seen that *A. conyzoides* will not undergo significant range changes under RCP 4.5 for 2050 and 2070 but will experience significant changes under RCP 8.5 2050 and 2070 predominantly governed by a reduction in habitat

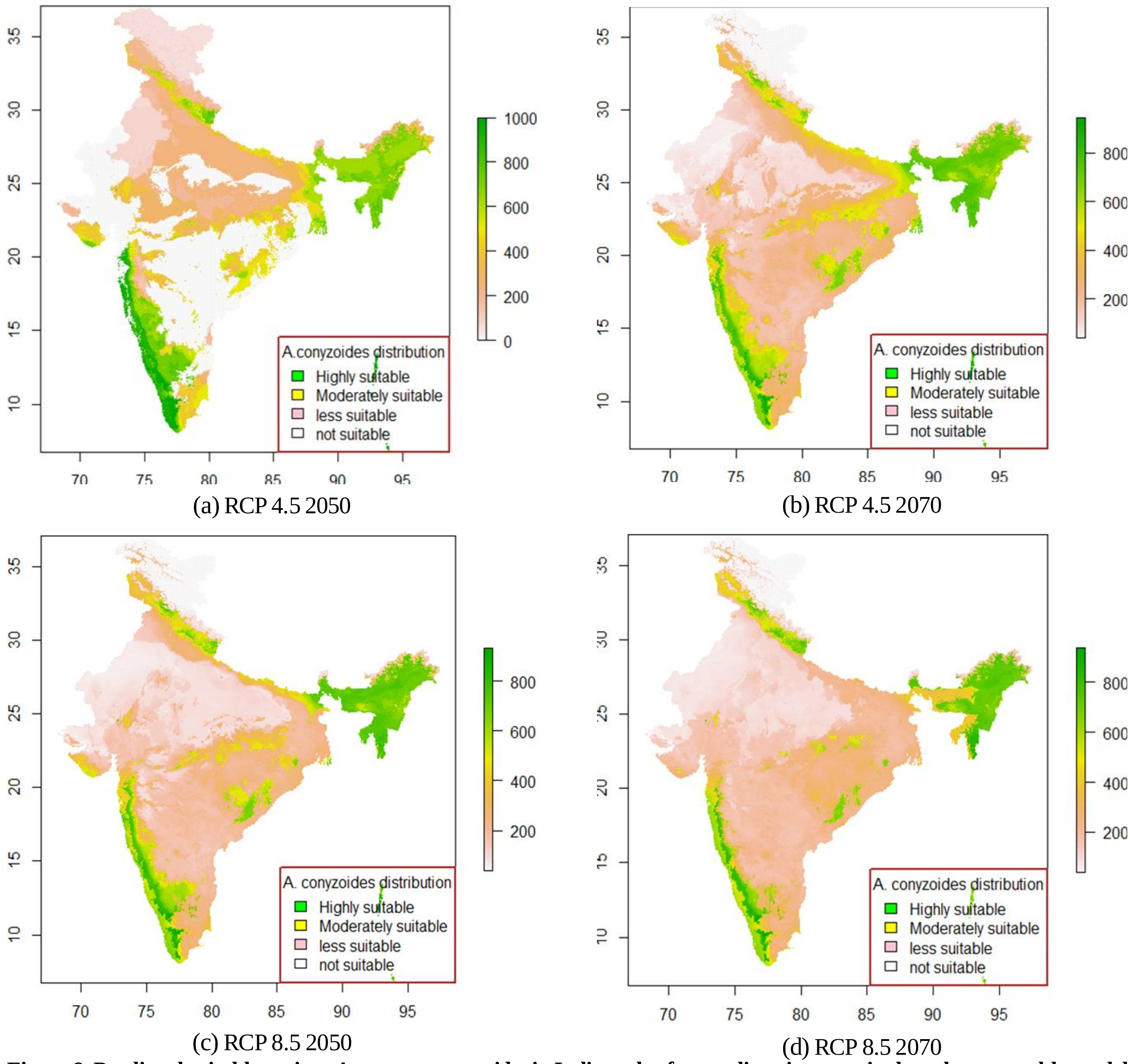


Figure 9. Predicted suitable regions *Ageratum conyzoides* in India under future climatic scenarios based on ensemble model

Table 6. Summary of the range change statistics for the *Ageratum conyzoides* under different climate change scenarios compared to current climatic conditions

Scenario	Loss %	Gain %	Change %
RCP 4.5 2050	27.211	29.096	1.885
RCP 4.5 2070	31.128	28.32	-2.808
RCP 8.5 2050	36.342	17.275	-19.067
RCP 8.5 2070	57.397	15.668	-41.73

suitability for weeds. It is observed that invasion hotspots for *A. conyzoides* will be completely shifted towards north- eastern side of the country.

Conclusion

The study highlights the potential impact of climate change on the distribution of *Trianthema portulacastrum* and *Ageratum conyzoides* in India under present and future climatic conditions. The significant contribution of bioclimatic variables such as temperature seasonality, annual mean temperature, and minimum temperature of the coldest month was found to govern the potential distribution of *T. portulacastrum* and *A. conyzoides*. Suitable regions for *T. portulacastrum* are predicted to increase under RCP 4.5 and 8.5 for the years 2050 and 2070, whereas for *Ageratum conyzoides*, suitable regions in India will not undergo significant range change under RCP 4.5 but will decrease under RCP 8.5 for the years 2050 and 2070. This study can aid in the management of weeds in the potentially identified areas as hotspots in climate change, and the findings could be utilised as a preventative strategy to establish early detection and rapid reaction or to develop one if none currently exists. Ensemble modelling was used here and is certainly reliable in estimating species distributions, and it is useful in biodiversity planning and management.

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RESEARCH NOTE

Assessing weed competitive abilities of rice genotypes in direct-seeded rice using purple rice as model weed

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ABSTRACT

Studies were undertaken to evaluate the influence of crop-weed competition period and genotypes on crop emergence, vigour, growth, yield attributes, yield and weed growth in direct-seeded rice during rainy season (*Kharif*) 2020 at Punjab Agricultural University, Ludhiana, India. The experiment comprising four crop-weed competition period *viz*; Weedy throughout (WT), Weed free up to 15 days (WF15), Weed free up to 30 days (WF30) and weed free throughout (WF-Th) in main plots; and eight genotypes (*RYT 4004, RYT 4005, RYT 4079, RYT 4080, RYT 4081, PR 120, PR 126 and SAVA 134*) in sub-plots with 3 replications was laid out in split plot design. The competition to the crop was imposed through purple rice. It is evident that keeping the crop weed free up to 30 days recorded crop emergence, vigour, yield attributes and yield similar to that of weed free throughout treatment. Among genotypes, *SAVA 134, PR 120* and *PR 126* were found to be weed suppressive and high yielding genotypes. Although *RYT 4081* was also weed suppressive but gave the least grain yield. Among various traits, grain yield (-1.5437) exerted very high negative direct effect *fb* leaf area index (LAI) at 7 DAS (-0.9185) *fb* plant tillers at physiological maturity (-0.8908) on DMA by surrogate weed at physiological maturity. All the parameters namely; root length (7 DAS), plant height (30 DAS), plant tillers (60, 90 DAS and physiological maturity), flag leaf area, number of leaves/plant (60 DAS), DMA (30 DAS), dry matter partitioning to panicles (at anthesis), panicles/m^2 and straw yield exerted high negative indirect effect through grain yield as well as LAI (7 DAS) on surrogate weed DMA at physiological maturity.

Keywords: Crop-weed competition period, Flag leaf area (FLA), Genotypes, Physiological maturity (PM), Purple rice

Rice is one of the most important cereal crops worldwide as it serves as the basis of life for half of the global population (Khir and Pan 2019). Higher production of rice is necessary for food security. Globally, more than 50% rice area follows puddled transplanting method for cultivation of rice (Dass *et al*. 2016). But now, as a result of the looming water crisis and shortage of labour, farmers in Asia are considering dry direct-seeding as a good alternative to transplanting (Dhillon and Mangat 2018, Dhillon *et al*. 2021), where, rice crop is established by drilling the rice seeds directly in the field. It is reported that DSR saves 12-60% of irrigation water, 8-60% in labour, reduce global warming potential by 32-44%, cost of cultivation by ₹ 6436-7950/ha and results in better wheat yield (8-10%) than puddled transplanted rice (PTR) (Kumar and Ladha, 2011, Kumar and Harikesh 2018, Bhullar *et al*. 2018, Ranbir *et al*. 2019, Basavalingaiah *et al*. 2020). However, weeds are the major bottleneck in realizing the yield potential of direct-seeded rice (Dhillon *et al*. 2021a).

Transplanted rice has a greater competitive advantage over weeds that emerge after transplanting; but in direct seeding, the rice plants compete with the weeds from the time they emerge. Weeds being hardy and have profuse root and shoot growth habit, grow faster than rice and thereby check the growth of rice by severe weed crop competition in critical crop-weed competition period. Herbicide have been proven to be the most effective way in controlling weeds, but intensive herbicide use can cause environmental contamination and may increase the risk of herbicide resistance in weeds (Heap 2014). With the increased herbicide use, risk of herbicide resistance, shifting of weed flora, rising costs of production and environmental contamination are major concerns, creating an interest for exploring cultural (non-chemical) method of weed control (Chauhan 2012).

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Hence, ecological approach like selection of weed competitive genotypes is an important non-monetary practice, which can be exploited as an integrated tool for reducing herbicide costs, minimize environment degradation and delay the evolution of herbicide resistance in weeds (Dhillon *et al.* 2021b). Growing of genotypes in the presence of weeds can help to evaluate their weed competitiveness. Weed competitive genotypes have the ability to maintain higher yields despite weed competition. For this purpose, a model weed with morphologically different characters can serve better as; it will be easy to distinguish between weedy and weed free treatments and there will be ease in carrying out different crop-weed competition regimes. Purple rice (*Oryza sativa*) has already been used as a model weed for screening of genotypes for weed competitiveness in earlier studies at Internationonal Rice Research Institute (IRRI). It is an IRRI rice cultivar that is used as a boundary marker in rice plant breeding experiments as its plants are easily distinguishable from ordinary rice plants due to its burgundy foliage colour. Among the weed species *Echinochloa* spps. are the predominant grass weeds in rice. Purple rice is one of the best suited models weed for screening of weed competitiveness as a replacement to *E. crus-galli* owing to its maximum height comparable to that of *E. crus-galli*, the main weed species in rice (Bastiaans *et al.* 1997). Therefore, a study was conducted during rainy season (*Kharif*) of 2020 to screen the weed competitive potential of rice genotypes against purple rice (a surrogate weed) in direct-seeded rice.

The experiment was conducted during *Kharif* 2020 at the Research Farm, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, India [30°56' N latitude; 75°52' E longitude; 247 m altitude] located in the Indo–Gangetic Plains Region (IGPR). Climate of experimental site is characterized as sub-tropical, semi–arid with an annual rainfall of 733 mm, out of which about 80% is received from June to September. Rainfall, maximum and minimum temperatures were measured at agro–meteorological observatory of PAU, Ludhiana situated at 200 m from the experimental site. The experimental site was Typic Ustipsamment (Fatehpur sandy–loam), low in available–N (265.0 kg/ha), high in available–P (31.9 kg/ha) and medium in available–K (136 kg/ha) and organic carbon (0.42%). The soil pH and electrical conductivity were within the normal range.

The experiment was laid out in split plot design keeping four crop-weed competition periods [weedy throughout (WT), weed free up to 15 days (WF15), weed free up to 30 days (WF30) and weed free throughout (WF-Th)] in main plot and eight genotypes (*RYT 4004, RYT 4005, RYT 4079, RYT 4080, RYT 4081, PR 120, PR 126 and SAVA 134*) in sub plots. Purple rice was used as surrogate weed in this experiment to evaluate the weed competitiveness of the rice genotypes. Seeds were sown in proper moisture conditions (locally known as *vattar* DSR method or soil mulch DSR). Pre-sowing irrigation was applied in a well-prepared soil followed by shallow tillage when field reaches *vattar* (field capacity) condition and then rice sowing was done by *pora* method (when seeds are kept in a funnel, they gradually descend through the pointed ends that pierce the ground, planting themselves deeply) on June 15, 2020 at row spacing of 20 cm using a seed rate of 20 kg/ha in plots measuring 12-meter square. First post-sowing irrigation was applied 15 days after sowing. Subsequent irrigations were scheduled as per the crop demand at weekly interval. All other production and protection technologies were followed as per recommendations of Punjab Agricultural University, Ludhiana (Anonymous 2020).

Daily emergence counts until the plant population became constant were recorded from each plot, from 1 m row and emergence rate index (ERI) was calculated using formula suggested by Bartlett (1937). Ten seedlings from each replication of each plot were taken randomly at 7 and 15 DAS and seedling vigour indices (VI-2 and VI-2) were measured as suggested by Abdul-Baki and Anderson (1973).

The various dry matter partitioning indices were calculated as under:

a) **Dry matter translocation (DMT)**: The DMT during reproductive period was calculated as per following formula given by Cox *et al.*(1986):

$$DMT = \text{Total DM}_{(\text{at anthesis})} - (DM_{(\text{leaf})} + DM_{(\text{culm})} + DM_{(\text{chaff})})$$ at physiological maturity

Where, $DM_{(\text{leaf})}$ is the dry matter of leaves, $DM_{(\text{culm})}$ is the dry matter of culm and $DM_{(\text{chaff})}$ is the dry matter of culm at physiological maturity.

b) **Dry matter translocation efficiency (DMTE)**:

$$DMTE\ (\%) = \frac{DMT}{\text{dry matter at anthesis}} \times 100$$

c) **Contribution of pre-anthesis DM remobilization to grain (CDMRG)**

$$CDMRG = \frac{DMT}{DM(\text{grain})} \times 100$$

Where, DM $_{(grain)}$ is the DM of grain at physiological maturity.

Number of panicles were counted from one meter marked row of each plot and expressed as panicle/m^2. For estimating grain yield, a net area of 7.8 m^2 (6 rows X 6.5 m) was harvested from each plot and then threshed, sun dried, winnowed, cleaned and weighed on the electronic balance. For valid comparison of different treatments, moisture content in grains was estimated using digital moisture meter (Kett's RICETER J handheld grain moisture meter). Grain yield was adjusted at 14% moisture and expressed as t/ha. For estimating straw yield, the weight of straw from each net plot was recorded three days after harvest for estimation of straw yield, which was expressed as t/ha.

Data were subjected to analysis of variance (ANOVA) using statistical software (SAS 9.3.). Treatment means were compared using Tukey's test at p d" 0.05. The path coefficient analysis was done according to the method given by Wright (1921) and elaborated by Dewey and Lu (1959).

Effect on crop

Emergence and vigour studies: Results (**Figure 1**) show that weed free treatments (*i.e.,* WF15, WF30 and WF-Th) recorded higher values for ERI, VI-I &II (at 7 and15 DAS) and leaf area index (LAI) at 7 DAS. Although at 7 DAS, LAI and VI-I and II failed to show significant differences among crop-weed competition periods. Among genotypes (**Figure 1**), *PR 120*, *PR 126* and *SAVA 134* consistently recorded higher values for these parameters as compared to rest of the genotypes. Data reveal that, *PR 120* recorded the highest LAI at 7 DAS, *PR 126* recorded the highest VI-I at 15 DAS while the highest VI-I & II at 7 DAS and VI-II at 15 DAS was recorded by *SAVA 134*. However, all these were statistically similar in case of ERI. The genotype *RYT 4079* recorded the least values for these parameters.

The higher values of dry matter partitioning indices were recorded in *SAVA 134* but also in *RYT*

Table 1. Effect of crop-weed competition period and genotype on dry matter partitioning indices of crop

Treatment	DMT (g/m^2)	DMTE (%)	CDMRG (%)
Crop-weed competition period			
Weedy throughout (WT)	183.7	29.51	37.8
Weed free up to 15 days (WF15)	255.1	29.45	43.6
Weed free up to 30 days (WF30)	374.1	34.32	52.6
Weed free throughout (WF-Th)	390.7	34.55	52.5
LSD (p=0.05)	61.8	NS	10.0
Genotypes			
RYT 4004 (G_1)	189.7	22.8	30.8
RYT 4005 (G_2)	201.5	26.4	30.3
RYT 4079 (G_3)	266.6	33.5	50.4
RYT 4080 (G_4)	180.6	25.9	25.4
RYT 4081 (G_5)	216.9	25.7	61.3
PR 120 (G_6)	332.7	33.1	52.2
PR 126 (G_7)	459.1	43.5	61.0
SAVA 134 (G_8)	560.2	44.6	61.3
LSD (p=0.05)	101.2	7.89	18.8

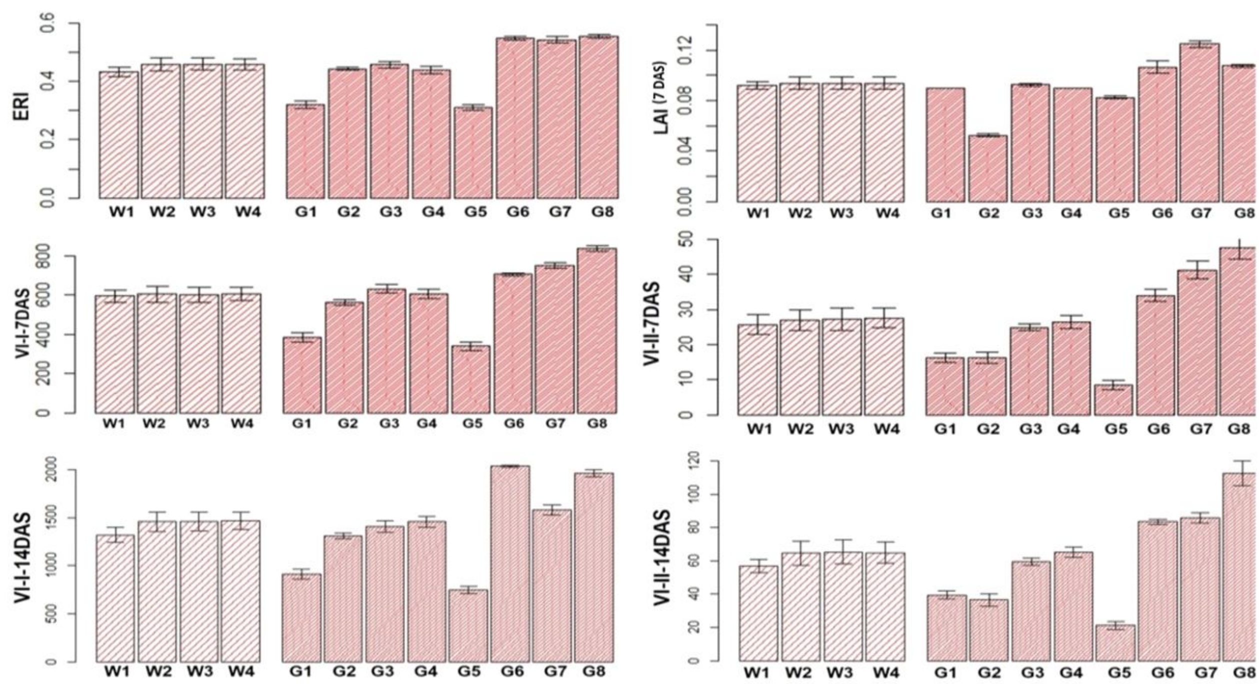

Figure 1. Effect of crop-weed competition period and genotype on emergence and vigour studies of crop

4081 in case of CDMRG (**Table 1**). It was noted that *SAVA 134* was at par with *PR 126* for DMT, DMTE, however, for CDMRG both *SAVA 134* and *RYT 4081* showed statistical parity with *RYT 4079, PR 120* and *PR 126* (**Table 1**). Dry matter partitioning indices (DMT and CDMRG) were the highest under weed free throughout treatment which was at par with weed free up to 30 days in case of DMT but also with weed free up to 15 days in case of Contribution of pre-anthesis DM remobilization to grain (CDMRG, Table 1). However dry matter translocation efficiency (DMTE) could not vary significantly with crop-weed competition periods.

All the yield attributes were observed to be the highest under weed free throughout treatment (**Table 2**). It was further evident that all yield attributes were statistically similar under weed free throughout and weed free up to 30 days treatment but yield attributes namely; panicle weight, and 1000-grain weight revealed statistical parity with weed free up to 15 days treatment also. Weedy throughout recorded the least value for all the yield attributes. It was further observed that keeping the crop weed free up to 30 days gave grain and straw yield similar to that of full season weed free treatment (**Table 2**). The better growth and development in weed free throughout treatment can be explained in light of the fact that this treatment recorded better emergence, early vigour (**Figure 1**). No competition for resources by surrogate weed in this treatment resulted in better crop growth along with favorable growth attributes data not presented). Many parameters namely; plant tiller count, number of leaves/plant, CGR, dry matter partitioning indices, panicles/m^2, number of filled and unfilled grains/panicle, panicle fertility, grain and straw yield showed statistical parity between weed free throughout and weed free up to 30 days treatment. The results are in harmony with that of Oudhia and Tripathi (2000), who reported that reducing the competition improves the growth and development of rice and ultimately leading to better yields.

Table 2. Effect of crop-weed competition period and genotype on yield attributes of crop

Treatment	Panicles /m^2	Panicle weight (g)	Panicle fertility (%)	1000-grain weight (g)
Crop-weed competition period				
WT	227.8	2.87	84.9	23.8
WF15	283.7	3.13	87.8	25.1
WF30	335.5	3.28	89.1	25.1
WF-Th	343.4	3.34	89.9	25.2
LSD (p=0.05)	8.9	0.22	0.5	0.3
Genotypes				
RYT 4004 (G_1)	293.0	3.17	91.2	27.2
RYT 4005 (G_2)	286.1	3.14	89.5	26.8
RYT 4079 (G_3)	252.1	3.18	87.7	23.6
RYT 4080 (G_4)	286.8	3.22	89.7	26.8
RYT 4081 (G_5)	242.1	2.82	72.6	24.5
PR 120 (G_6)	365.3	2.79	89.4	24.0
PR 126 (G_7)	326.1	3.14	91.5	22.5
SAVA 134 (G_8)	329.3	3.78	91.9	22.9
LSD (p=0.05)	17.9	NS	NS	NS

Among genotypes, it was found that *PR 120* was superior in terms of panicles/m^2 which was significantly *fb SAVA 134* and *PR 126* (both being statistically similar with each other) (**Table 2**). The highest number of filled grains/panicle coupled with the least number of unfilled grains/panicle (data not presented) in case of *SAVA 134* resulted in the highest panicle weight and panicle fertility. Panicle fertility of *SAVA 134* was statistically similar with that of *RYT 4004* and *PR 126*. It was further observed that *SAVA 134* (rice hybrid) recorded significantly the highest grain yield, whereas *RYT 408*1 recorded the lowest

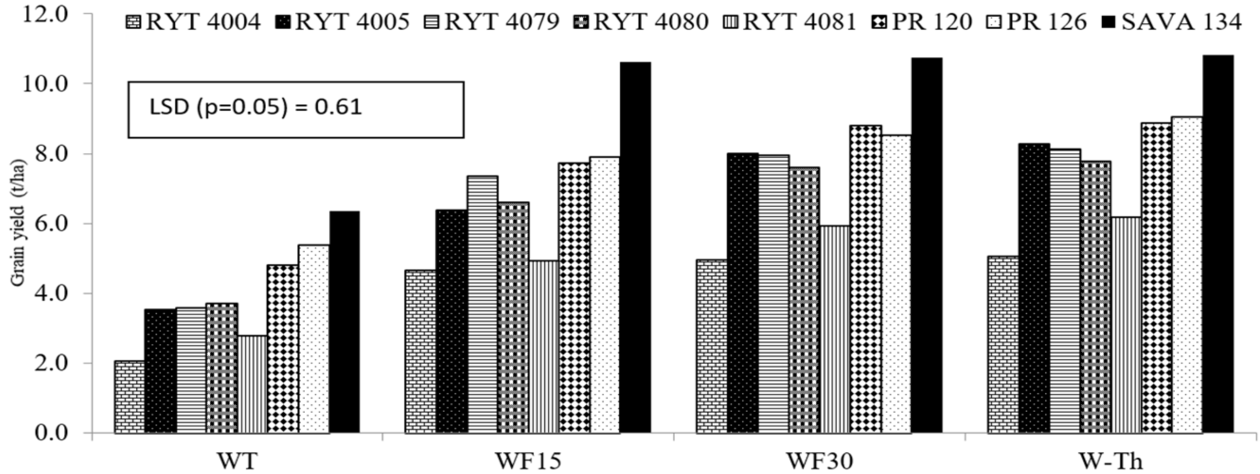

Figure 2. Interaction effects of crop-weed competition period and genotype on grain yield (t/ha) of rice

grain yield (**Table 3**). The range of grain, straw yield and HI among different genotypes was found to be 4.18-9.64 q/ha, 8.27-13.04 q/ha and 3.16-4.52%, respectively. *SAVA 134* was significantly followed by *PR 120* and *PR 126*, which were statistically similar to each other. However, the highest straw yield was recorded in *PR 120*, which was significantly superior over rest of the genotypes. The highest HI was found in PR 126, which was statistically similar *to RYT 4080* and *SAVA 134*.

Among genotypes, variation was observed *w.r.t.* all the parameters; emergence, vigour, yield attributes, yield, weed suppression. These results are in harmony with that of Shrestha *et al.* (2021a and b), who reported variation among rice genotypes for growth and development. Genotypes; *SAVA 134, PR 120* and *PR 126* recorded higher values for all the parameters for crop emergence, vigour, and yield than rest of the genotypes (**Figure 1** and **Table 1-3**). Higher growth and development in former genotypes resulted in better weed suppression by them. Higher grain yield in *SAVA 134* (rice hybrid) can be explained in light of the fact that hybrid rice is considered better yielder, which is in corroboration of our findings (Chauhan *et al.* 2012).

Data on interactive effects of crop weed competition period and genotypes on number of panicles m^{-2} indicate that *SAVA 134* recorded similar number of panicle m^{-2} under different crop weed competition periods i.e., weed free up to 15 days (WF15) and 30 days (WF30) as well as full season weed free treatment (WF-Th) (**Table 4**). However, all other genotypes showed statistical similarity between treatments of weed free up to 30 days (WF30) and weed free throughout (WF-Th) only (**Table 4**)

Likewise, data on grain yield brings out that across the genotypes, there were significant differences in grain due to different crop-weed competition periods except WF-Th and WF30, which were statistically similar to each other. But in case of *RYT 4005*, WF15 yielded similar to that of WF30 but keeping the crop WF-Th the season caused significant enhancement in grain yield. Data also brings out that in case of *RYT 4081* and *SAVA 134*, keeping the crop weed free only up to 15 days, yielded similar to that of full season weed free treatment (WF-Th) (**Figure 2**).

Effect on surrogate weed (purple rice): With regards to weed indices, the highest and lowest weed index (WI) values were exhibited by weedy throughout (50.7%) and weed free up to 30 days (3.5%), respectively (**Table 5**). The highest weed control efficiency (WCE) of 100% was recorded in weed free throughout, which was significantly followed by weed free up to 30 days (91.1%). Weed free up to 15 days showed the least WCE (74.1%). However, weed competitive index (WCI) could not vary significantly due to crop-weed competition period.

The lowest WI was recorded *in SAVA 134*, which was significantly *fb PR 120* (**Table 5**). The highest WCE and WCI was recorded in *SAVA 134*, which was statistically similar to *RYT 4004 and RYT 4005, PR 120* and *PR 126* in case of WCE.

The interactive effects also bring out that all the genotypes recorded the highest WI in WT treatment which decreases under WF15 *fb* WF30. However, *RYT 4004, RYT 4005, RYT 4081, PR 120* and *SAVA*

Table 3. Effect of crop-weed competition period and genotype on grain and straw yield and harvest index (HI) of crop

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)
Crop-weed competition period			
Weedy throughout (WT)	4.04	6.38	38.3
Weed free up to 15 days (WF15)	7.02	10.13	40.8
Weed free up to 30 days (WF30)	7.75	11.13	40.9
Weed free throughout (WF-Th)	8.03	11.31	41.3
LSD (p=0.05)	0.34	0.99	1.8
Genotypes			
RYT 4004 (G_1)	6.75	9.19	41.9
RYT 4005 (G_2)	6.30	8.81	41.4
RYT 4079 (G_3)	4.96	8.65	36.6
RYT 4080 (G_4)	6.55	8.27	43.7
RYT 4081 (G_5)	4.18	8.85	31.6
PR 120 (G_6)	7.73	13.04	37.2
PR 126 (G_7)	7.54	9.19	45.2
SAVA 134 (G_8)	9.64	11.91	45.0
LSD (p=0.05)	0.30	0.10	2.4
Crop-weed competition period x Genotypes			
LSD (p=0.05)	0.61	NS	NS

Table 4. Interaction effects of crop-weed competition period and genotype on number of panicles/ m^2 of rice

Treatment	WT	WF15	WF30	WF-Th
RYT 4004 (G_1)	211.7	303.3	320.0	337.0
RYT 4005 (G_2)	257.3	273.7	298.3	315.0
RYT 4079 (G_3)	186.7	190.0	308.3	323.3
RYT 4080 (G_4)	185.0	206.7	373.3	382.3
RYT 4081 (G_5)	205.0	235.0	263.3	265.0
PR 120 (G_6)	268.3	380.0	406.0	406.7
PR 126 (G_7)	248.3	335.0	359.3	361.7
SAVA 134 (G_8)	260.0	346.0	355.0	356.0
LSD (p=0.05)		CWCP × G: 17.9		

Table 5. Effect of crop-weed competition period and genotype on weed indices

Treatment	Weed index (%)	Weed control efficiency (%)	Weed competitive index
Crop-weed competition period			
Weedy throughout (WT)	50.7	-	1.09
Weed free up to 15 days (WF15)	12.9	74.1	1.43
Weed free up to 30 days (WF30)	3.5	91.1	1.38
Weed free throughout (WF-Th)	-	100.0	-
LSD (p=0.05)	6.3	4.8	NS
Genotypes			
RYT 4004 (G_1)	22.4	88.7	1.12
RYT 4005 (G_2)	25.6	87.7	0.91
RYT 4079 (G_3)	26.4	85.0	0.55
RYT 4080 (G_4)	27.7	84.5	0.69
RYT 4081 (G_5)	22.8	85.8	0.61
PR 120 (G_6)	19.0	91.7	2.07
PR 126 (G_7)	20.1	91.1	1.39
SAVA 134 (G_8)	14.7	92.6	3.06
LSD (p=0.05)	4.4	5.9	0.50
Crop-weed competition period x Genotypes			
LSD (p=0.05)	7.6	NS	NS

134 recorded statistically similar weed index for WF15 and WF30. It was further evident that SAVA 134 kept weed free up to 15 days recorded the WI similar to all other genotypes kept weed free up to 30 days (**Table 6**).

Path analysis

The path analysis between crop traits has been presented in **Table 7**. Data reveal that grain yield (-1.5437) exerted very high negative direct effect *fb* LAI at 7 DAS (-0.9185) *fb* plant tillers at physiological maturity (-0.8908) on DMA by surrogate weed at physiological maturity. So, traits like LAI at 7 DAS, plant tillers at physiological maturity, number of leaves at 60 DAS and grain yield exerted direct negative effect on weed DMA at physiological maturity. All the parameters namely; root length (7 DAS), plant height (30 DAS), plant tillers (60, 90 DAS and physiological maturity), flag leaf area, number of leaves plant^{-1} (60 DAS), DMA (30 DAS), dry matter partitioning to panicles (at anthesis), panicles m^{-2} and straw yield exerted high negative indirect effect through grain yield and LAI (7 DAS) on weed DMA at physiological maturity. Similarly, panicles/m^2, plant tillers (60 and 90 DAS) also exerted high negative indirect effect through plant tillers (physiological maturity) on weed DMA at physiological maturity.

Table 6. Interaction effects of crop-weed competition period and genotype on weed index

Treatment	WT	WF15	WF30
RYT 4004 (G_1)	55.8	9.4	2.1
RYT 4005 (G_2)	52.5	15.3	9.4
RYT 4079 (G_3)	54.8	20.3	4.1
RYT 4080 (G_4)	57.1	22.8	3.2
RYT 4081 (G_5)	58.8	7.7	2.0
PR 120 (G_6)	39.2	12.3	5.6
PR 126 (G_7)	45.9	13.5	0.8
SAVA 134 (G_8)	41.4	1.9	0.7
SEm±		CWCP × G: 3.7	
LSD (p=0.05)		CWCP × G: 7.6	

Plant competitiveness is thought to be controlled by morphological, physiological, and biochemical traits. Rice genotype with strong weed competitiveness is a low-cost safe strategy for weed management (Singh *et al.* 2016). Rice characteristics related with weed competitiveness include seed size, emergence rate, plant height, early and vigorous growth rate, high tiller number, droopy leaves, high biomass accumulation at early stages, high leaf area index (LAI), rapid ground cover by canopy, high specific leaf area during vegetative growth, deep and prolific roots, resistance to biotic and abiotic stresses and early maturity etc. (Dhillon *et al.* 2021b). Our data also corroborate the above findings (**Figure 1**).

Table 7. Direct and indirect effects of various crop traits on weed dry matter accumulation at physiological maturity (WDMPM)

Treatment	RL 7	LAI 7	PH 30	PT 60	PT 90	PT PM	FLA	LN 60	DMA 30	DMPPA	P/m^2	GY	SY	WDMPM
RL 7	**0.4035**	-0.0668	-0.0973	0.0404	0.0232	-0.0722	-0.0467	-0.2712	0.3770	0.2085	0.0435	-0.9018	0.0254	-0.3346
LAI 7	0.0293	**-0.9185**	-0.0652	0.4167	0.1292	-0.4993	-0.1056	-0.2426	0.5532	0.3535	0.3638	-0.6224	0.0272	-0.5806**
PH 30	0.1819	-0.2776	**-0.2158**	0.3685	0.1146	-0.5876	-0.1531	-0.4523	0.6095	0.3504	0.3741	-1.0355	0.0338	-0.6891**
PT 60	0.0242	-0.5688	-0.1182	**0.673**	0.1846	-0.7733	-0.1536	-0.4673	0.7478	0.3728	0.6265	-1.1852	0.0382	-0.5993**
PT 90	0.0456	-0.5789	-0.1206	0.6057	**0.2051**	-0.7562	-0.1416	-0.4820	0.8020	0.3287	0.5711	-1.1334	0.0380	-0.6164**
PT PM	0.0327	-0.5148	-0.1423	0.5842	0.1741	**-0.8908**	-0.1426	-0.4386	0.6836	0.3028	0.6067	-1.0001	0.0437	-0.7015**
FLA	0.0946	-0.4872	-0.1660	0.5193	0.1459	-0.6381	**-0.1991**	-0.4623	0.6888	0.4706	0.4826	-1.2447	0.0298	-0.7658**
LN 60	0.1887	-0.3843	-0.1683	0.5425	0.1705	-0.6739	-0.1587	**-0.5797**	0.7757	0.3806	0.5191	-1.3519	0.0413	-0.6986**
DMA 30	0.1672	-0.5584	-0.1446	0.5531	0.1808	-0.6693	-0.1507	-0.4943	**0.9098**	0.3766	0.5145	-1.3750	0.0436	-0.6467**
DMPPA	0.1468	-0.5668	-0.1320	0.4379	0.1177	-0.4708	-0.1635	-0.3852	0.5980	**0.5729**	0.384	-1.1226	0.0222	-0.5613**
P/m^2	0.0269	-0.5128	-0.1239	0.6471	0.1797	-0.8294	-0.1474	-0.4619	0.7184	0.3376	**0.6516**	-1.1212	0.0403	-0.5950**
GY	0.2357	-0.3703	-0.1448	0.5167	0.1506	-0.5771	-0.1605	-0.5077	0.8104	0.4166	0.4732	**-1.5437**	0.0405	-0.6604**
SY	0.1823	-0.4451	-0.1299	0.4575	0.1388	-0.6939	-0.1057	-0.4263	0.7070	0.2269	0.4675	-1.1136	**0.0561**	-0.6785**

Conclusion

It can be inferred that keeping the direct-seeded rice crop weed free up to 30 days can result in yield realization similar to that obtained by full season weed free crop. Among tested genotypes, *SAVA 134*, *PR 120* and *PR 126* were found to be weed suppressive and high yielding genotypes. For attaining an effective weed management strategy, DSR breeding should be focused on traits namely; grain yield, LAI at 7 DAS, root length (7 DAS), flag leaf area, number of leaves / plant (60 DAS), DMA (30 DAS), dry matter partitioning to panicles (at anthesis) and panicle/m^2.

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RESEARCH NOTE

Weed dynamics and maize productivity as influenced by sole and tank mix application of herbicides

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ABSTRACT

A field experiment was conducted during rainy season of 2018 in Norman. E. Borlaug. Crop Research Centre of GBPUA&T, Pantnagar with the objective to find the best weed control method among the application of herbicides alone, their tank mix application, sequential application and integration with cultural methods to control the complex weed flora of *Kharif* (rainy) maize and to study its effect on the growth and yield. The experiment was laid out in a randomized block design with three replications and ten treatments, *viz.* atrazine 1.0 kg/ha, tembotrione 120 g/ha, halosulfuron-methyl 67.5 g/ha, atrazine 1.0 kg/ha *fb* halosulfuron-methyl 54 g/ha, atrazine 800 g/ha *fb* halosulfuron-methyl 67.5 g/ha, tembotrione 120 g/ha + halosulfuron-methyl 54 g/ha, tembotrione 96 g/ha + halosulfuron-methyl 67.5 g/ha, atrazine 1.0 kg/ha *fb* one hand weeding at 25 DAS, weed free and weedy check. Among the weed control treatments, pre-emergence application of atrazine 1.0 kg/ha followed by one hand weeding at 25 DAS was the best weed control method which significantly reduced total weed density as well as total dry matter and significantly increased grain and straw yield, weed control efficiency and B:C ratio. This treatment bargained the yield reduction at 3.1% as compared to weedy check (53.1%) reducing the crop-weed competition. Tank mix application of tembotrione 120 g and halosulfuron-methyl 54 g/ha at 3-4 leaf stage of weeds was found to be at par to this treatment.

Keywords: Halosulfuron-methyl, *Kharif* maize, Tank application, Tembotrione, Weed density, Weed dry matter, Weed control efficiency

Maize (*Zea mays*) is one of the most important cereal crops occupying third position in the world after wheat and rice. In India, maize is being cultivated on 9.22 million hectares area, with a production of 28.78 million tonnes and average productivity of 3.12 tonnes per hectare (Nayak *et al.*, 2023). In India major area of maize production falls under *Kharif* (rainy) season which is characterized by heavy rains and high humidity, providing congenial environment for the insect, pest, diseases and weed infestation. Maize crop gets infested with different types of weeds. Some of the grass weeds found in the maize fields of sandy loam soil of Uttarakhand were *Echinochloa colona* L., *Digitaria sanguinalis* L. and *Brachiaria ramosa* L. and broad-leaved weeds were *Phyllanthus niruri* L., *Cleome viscosa* L. and *Trianthema monogyna* L. and *Cyperus rotundus* L. was the most common sedge (Singh *et al.* 2012).

Conventional method of weed control becomes quite difficult and uneconomical in *Kharif* maize due to slushy and hard field conditions as a result of continuous rains and labour scarcity. Hence, chemical method of weed control becomes more feasible, less laborious, cost effective and economical, especially in maize grown in rainy season during June-July (*Kharif*). However, application of sole herbicide under diverse and mixed weed flora does not provide satisfactory weed control (Nath *et al.* 2020). Moreover, continuous usage of same herbicide or similar herbicides year after year results in weed shift as well as herbicide resistance in weed species. So for broad spectrum weed control, use of more than one herbicide should be done, either by mixing them or by using them in temporal variation *i.e.* pre and post-emergence herbicides. Farmers at present are applying atrazine 1.0 kg/ha as pre-emergence herbicide but atrazine is unable to control many weeds such as *Echinochloa colona* and *Cyperus rotundus* (Singh *et al.* 2015). Hence it is necessary to widen the scope of atrazine by applying it with some other herbicides either as mixture or in sequence. Halosulfuron-methyl is a selective, post-emergence herbicide very effective in controlling sedges and some broad-leaf weeds. Kumar (2018) reported that application of halosulfuron-methyl at 67.5 g/ha 15 days after treatment reported significantly less population of *Cyperus rotundus.* Tembotrione is a post-emergence herbicide which inhibits 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme and the biosynthesis of

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plastoquinone and subsequently carotenoid pigment formation and chlorophyll disruption (Porter *et al*. 2005). It controls broad as well as grass weeds. Tank mix application of tembotrione with lower dose of atrazine has been reported to be more effective providing broad spectrum weed management than their sole application. So, there is a need to evaluate alternate post-emergence herbicide which can provide broad spectrum weed control in maize in Indian situation. Hence, an experiment was undertaken to find out the most effective and economic herbicide and its optimum dose for minimizing the menace of weeds in *Kharif* maize.

The field experiment was conducted during the *Kharif* season of 2018 in the D-3 block of NE Borlaug Crop Research Centre of G. B. Pant University of Agriculture and Technology (GBPU&T), Pantnagar. Soil type at the experimental site was clay loam in texture, almost neutral in reaction (pH- 7.2) and medium in organic carbon (0.57%). Available N, P and K content in soil was 211.5, 21.3 and 192.5 kg/ha, respectively. Hybrid maize variety '*NMH – 589*' (*Suvarna*) was sown on 27th June, 2018 at spacing of 60 × 20 cm and harvested on 9th October, 2018. Crop was fertilized with 120: 60:40 kg/ha of N, P and K, respectively. Herbicides were sprayed using 750 litres of water per hectare for pre-emergence herbicides (atrazine) and 500 litres of water per hectare for post-emergence herbicides with the help of Maruti foot sprayer fitted with flat fan nozzle. In weed free plots, weeds were removed with the help of khurpi (hand operated small spade) as and when required to keep the plot free from weeds. Weedy plot remained infested with the native weed population throughout the crop growing season. Data on weed density and dry matter, crop growth and yield were recorded. Weed control efficiency and weed index were calculated. Weed data were square root transformed before statistical analysis.

Total weed density and dry matter

The experimental field was infested with 14 weeds species which consisted 5 grass weeds, 8 broad-leaved weeds and 1 sedge. The major weed flora of the field consists of three grass weeds, *viz. Echinochloa colona, Dactyloctenium aegyptium, Digitaria sanguinalis*, three broad-leaf weeds *viz.*, *Celosia argentea, Trianthema monogyna* and *Cyperus rotundus* as a major sedge. *Cyperus rotundus* was the major weed of the maize field which contributed 33.5, 38.9 and 39.7 per cent of the total weed density at 30th, 60th and 90th day stage of the crop growth, respectively. Similar findings regarding the highest density of *Cyperus rotundus* in the maize field has also been reported by Shaik and Subramanyam (2017) and Dey *et al*. (2018).

The highest density of total weeds was recorded at 30th day stage in weedy check, which decreased at later stages (**Table 1**). Similar results of higher weed infestation at 30th day stage of maize have also been reported by Gupta *et al*. (2017) and Zimdahl (2004). All the weed control measures caused significant reduction in the density and dry weight of total weeds over weedy check (**Table 1**). Pre-emergence

Table 1. Effect of different treatments on weed density and dry matter of total weeds; weed control efficiency (WCE) at different crop growth stages and weed index (WI) in maize

Treatment	Dose (g/ha)	Weed density (no./ m^2)			Total weed dry matter (g/m^2)			WCE (%)			WI (%)
		30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	
Atrazine	1000	12.36 (152.0)	11.23 (125.3)	9.00 (80.0)	5.35 (27.70)	8.17 (69.95)	6.93 (47.11)	65.5	70.6	68.1	32.8
Tembotrione	120	9.07 (81.3)	7.98 (62.7)	6.50 (41.3)	3.54 (11.76)	5.82 (32.89)	4.64 (20.56)	85.4	86.2	86.1	20.3
Halosulfuron	67.5	13.10 (170.7)	11.53 (132.0)	9.43 (88.0)	6.69 (46.15)	13.66 (165.33)	9.58 (90.95)	42.6	30.6	38.5	43.8
Atrazine *fb* halosulfuron	1000 *fb* 54	6.38 (52.0)	5.97 (34.7)	4.27 (17.3)	2.96 (8.09)	5.16 (25.63)	3.69 (12.66)	89.9	89.2	91.4	12.5
Atrazine *fb* halosulfuron	800 *fb* 67.5	9.43 (88.0)	7.98 (62.7)	6.40 (40.0)	4.42 (18.70)	7.08 (63.35)	5.86 (36.88)	76.7	73.4	75.0	31.3
Tembotrione+ halosulfuron	120 + 54	5.38 (28.0)	4.27 (17.3)	3.00 (8.0)	2.13 (3.56)	3.59 (11.91)	2.37 (4.75)	95.6	95.0	96.8	9.4
Tembotrione + halosulfuron	96 + 67.5	7.81 (60.0)	6.30 (38.7)	5.00 (24.0)	3.50 (11.30)	6.09 (36.12)	4.52 (19.46)	85.9	84.8	86.8	17.2
Atrazine *fb* 1 hand weeding at 25 DAS	1000	1.0 (0.0)	3.96 (14.7)	1.92 (2.7)	1.0 (0.0)	2.23 (3.9)	1.41 (0.99)	100	98.3	99.3	3.1
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)	100	100	100	0.0
Weedy check		17.73 (318.7)	15.24 (238.7)	13.00 (174.7)	8.90 (80.36)	16.11 (238.3)	12.04 (147.8)	0.0	0.0	0.0	53.1
LSD (p=0.05)		2.66	1.81	1.3	1.38	3.24	1.75	-	-	-	-

application of atrazine 1.0 kg/ha followed by one hand weeding at 30 DAS was found to be the most effective treatment in controlling the weeds in maize crop. The next treatment in order was tank mix application of tembotrione 120 g and halosulfuron-methyl 54 g/ha applied at 3-4 leaf stage of weeds which was at par with pre-emergence application of atrazine 1.0 kg/ha *fb* halosulfuron-methyl 54 g/ha. Alone application of atrazine 1.0 kg/ha or tembotrione 120 g/ha or halosulfuron-methyl 67.5 g/ha were not found as effective as their tank mix application. Lowest total weed density and dry matter accumulation in pre-emergence application of atrazine 1.0 kg/ha followed by one hand weeding at 25 DAS has also been reported by Abdullah *et al*. (2016) and Deshmukh *et al*. (2014). This could be due to integrated weed management involving pre-emergence application of atrazine 1.0 kg/ha which led to inhibition of weed germination at initial stage of crop and hand weeding at later stage which completely controlled the late germinating weeds from further growth as reported by Gopinath and Kundu (2008). Lower density and dry matter accumulation of total weeds in tank mix application of tembotrione 120 g and halosulfuron-methyl 54 g/ha at 3-4 leaf stage of weed might be due to efficient control of grass and non-grass weeds with post-emergence application of tembotrione 120 g/ha and sedges with halosulfuron methyl 54 g/ha. Similar results of effective control of grass and non-grass weeds with the application of tembotrione 120 g/ha and sedges with halosulfuron methyl 67.5 g/ha has also been reported by Yadav *et al*. (2018) and Kumar (2018), respectively.

Weed control efficiency and weed index

Highest WCE was recorded under weed free condition at all the stages of crop growth, which was closely followed by pre-emergence application of atrazine 1.0 kg/ha followed by one hand weeding at 25 DAS. Similar result was obtained by Kumar *et al*. (2015). The next in order which recorded maximum WCE was with tank mix application of tembotrione 120 g and halosulfuron-methyl 54 g/ha at 3-4 leaf stage of the weeds, which was closely followed by pre-emergence application of atrazine 1.0 kg/ha *fb* halosulfuron-methyl 54 g/ha. Application of halosulfuron-methyl 67.5 g/ha at 3-4 leaf stage of weeds recorded lowest WCE at all the stages of crop growth. In weedy check, the highest yield reduction (53.1%) was reported out of crop-weed competition. Among the combination treatments, the lowest weed index was obtained in atrazine 1.0 kg/ha *fb* 1 hand weeding at 25 DAS (3.1%) followed by tembotrione 120 g and halosulfuron-methyl 54 g/ha at 3-4 leaf stage of the weeds (9.4%) and atrazine 1000 g/ha *fb* halosulfuron 54 g/ha (12.5%) whereas, among the sole application of herbicide treatments, tembotrione 120 g/ha was able to restrict the yield loss at 20.3% followed by atrazine 1000 g/ha (32.8%) and halosulfuron-methyl 67.5 g/ha (43.8%).

Yield, yield attributes and economics of *Kharif* maize

Uncontrolled growth of weeds in weedy check plot resulted in 53.1 and 49.6% reduction in grain and stover yield of maize, respectively when compared to weed free plot (**Table 2**). The grain as well as stover yield was severely reduced due to the weed- crop competition. Reduction in maize yield by 27-60% due to season long weed competition has also been reported by Kumar *et al.* (2015) and Jat *et al.* (2012). Among the weed control treatments, pre-emergence application of atrazine 1.0 kg/ha followed by one hand weeding at 25 DAS and tank mix application of tembotrione 120 g and halosulfuron-methyl 54 g/ha at 3-4 leaf stage of weeds yielded at par with weed free plot. Different yield attributing characters *viz.*, number of grains/row and number of grains/cobs in plots treated under these treatments was also at par with those under weed free condition. Significantly higher grain yield in pre-emergence application of atrazine 1.0 kg/ha followed by one hand weeding at 25 DAS has also been reported by Abdullah *et al*. (2016), Deshmukh *et al*. (2014) and Dixit and

Table 2. Effect of different treatments yield attributes, yield and economics of *Kharif* maize

Treatment	Dose (g/ha)	No. of grains/ row	No. of grains/cob	Grain yield (t/ha)	Stover yield (t/ha)	B:C ratio
Atrazine	1000	23.3	284.3	4.3	7.8	1.4
Tembotrione	120	25.5	339.2	5.1	9.4	1.7
Halosulfuron	67.5	21.1	242.7	3.6	6.6	0.9
Atrazine *fb* halosulfuron	1000 *fb* 54	26.2	356.3	5.6	9.9	1.9
Atrazine *fb* halosulfuron	800 *fb* 67.5	23.4	294.8	4.4	8	1.3
Tembotrione+ halosulfuron	120 + 54	26.9	371.2	5.8	10.2	1.8
Tembotrione + halosulfuron	96 + 67.5	25.6	340.5	5.3	9.6	1.6
Atrazine *fb* 1 hand weeding at 25 DAS	1000	28.2	394.8	6.2	11.2	2.1
Weed free		28.7	407.5	6.4	11.5	1.4
Weedy check		18.9	207.9	3	5.8	0.8
LSD (p=0.05)		4.4	72.8	0.7	1.5	

Gautam (1994). Higher crop yield in treatments where tank mix application of post-emergence herbicides might be due to broad spectrum weed control, which reduced the crop weed competition and led to increased crop growth and thereby increased the nutrient uptake by crop and ultimately higher grain and stover yield. Similar reports of increased nutrient uptake and yield of maize has been reported by Singh *et al.* (2005), Chopra and Angiras, (2008) and Shrinivas *et al.* (2014). Halosulfuron-methyl 67.5 g/ha at 3-4 leaf stage alone produced lowest grain yield. Application of both tembotrione 120 g/ha and halosulfuron-methyl 67.5 g/ha alone as post emergence produced lower yield than their tank mix application. The reduction in grain yields in plot treated with halosulfuron-methyl 67.5 g/ha at 3-4 leaf stage was particularly due to its very less effect on grass weeds and broad leaved weeds and tembotrione 120 g/ha on *Cyperus rotundus*.

The highest B: C ratio was recorded in pre-emergence application of atrazine 1.0 kg/ha followed by one hand weeding at 25 DAS. The next in line was pre-emergence application of atrazine 1.0 kg/ha *fb* halosulfuron-methyl 54 g/ha which was closely followed by tank mix application of tembotrione 120 g and halosulfuron-methyl 54 g/ha at 3-4 leaf stage of weeds. However the lowest B: C ratio was recorded in weedy check. Higher grain yield and lower cost of cultivation might have been responsible for the corresponding higher net returns and ultimately to higher B: C ratio. These weed control measures were more remunerative than weedy check with regard to net monetary returns hence gave higher B: C ratio. These results are in line with the findings of Roy *et al.,* (2008).

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RESEARCH NOTE

Effects of tank-mix herbicides on weed growth and maize productivity

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ABSTRACT

An experiment was carried out during 2021-22 at the Norman E. Borlaug Crop Research Center, G. B. Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar District, Uttarakhand to evaluate the effects of sequential and tank mix application of pre- and post-emergence herbicide on weed growth and performance of maize. Among the diverse weed flora observed, *Eleusine indica* L., *Digitaria sanguinalis* L., *Echinochloa colona* L. and *Eragrostis japonica* L. were dominant grassy weeds, where *Phyllanthus niruri* L., *Commelina benghalensis* L., *Cucumis melo* L. and *Cleome viscosa* L. were major broad-leaved weeds. *Cyperus rotundus* L. was the only sedge, where *Eleusine indica* dominated in the field during entire crop growth period. Chemical weed management through either sole application of topramezone and tembotrione or tank-mix application with atrazine recorded almost similar grain yield along with weed free check. The single tank mix application of atrazine - 0.75 kg/ha long with either tembotrione 120 g/ha or topramezone 25.2 g/ha at 15 DAS as single application can be recommended as a cost-effective method of weed control in maize owing to reduced weed biomass by 57.0 and 58.7%, respectively over weedy plot at 40 DAS while increased the grain yield by 41.6 and 46.7%, respectively under the respective treatments.

Keywords: Atrazine, Maize, Tembotrione, Tank-mix, Topramezone, Weed density, Weed dry matter

Maize (*Zea mays* L.) is a globally significant crop and ranks as one of the most important crops worldwide. In India, it is the third-largest crop in terms of production, following rice and wheat. In India, maize is cultivated over 9.57 million hectares (mha) area with a production of 28.8 million tonnes (mt) and productivity of 3.0 t/ha during the year 2019-20 (Indiastat 2021). Maize cultivation in India primarily takes place during the *Kharif* (rainy) season which is characterized by heavy rainfall and higher relative humidity, its wider rows provide ample space for weed growth, leading to severe competition and led to marked grain yield losses which was only 46.6% as compared to yield under weed free condition (Ehsas *et al*. 2016). Albeit, both manual removal and chemical application provide better weed control but become inaccessible under scarce labor at peak period of weed growth in case of former one, while not feasible under untimely rainfall in the latter situation. Increased incidence of untimed rainfall, non-uniform weed seed proliferation, and optimum soil moisture favor the weed flush emergence. Compared to sole application of atrazine, tank mix application along with new generation herbicides, *viz.* tembotrione and topramezone have been found effective for weed control in maize (Ghrasiram *et al.* 2020). The combined or sequential application of pre-emergence and/or post-emergence herbicides are necessary for effective weed control. Atrazine is widely used in maize crop for effective control over a broad range of weeds and can be applied both before and after emergence. Recently, two new post-emergence herbicides, tembotrione and topramezone have been introduced for effective control of both broad- and narrow-leaved weeds in maize within a short period of 2-5 days after treatment. Swetha *et al.* (2018) reported that the post-emergence application of tembotrione (105 g/ha) + atrazine (250 g/ha) at 15-20 days after maize sowing resulted in a significant reduction in weed biomass and higher weed control efficiency. These new generation herbicides have proven their potential to control diverse weed flora, their inclusion in crop cultivation ensure effective and swift weed control with ensured economic returns. Therefore, further exploration is needed to investigate the use of these new post-emergence herbicides (tembotrione and topramezone) in optimal combinations with atrazine to provide efficient and inclusive weed control in maize.

The study was designed to assess the effect of sequential and tank mix application of pre- and post-emergence herbicides on weed growth and

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performance of maize. The experiment was conducted in silty clay loam soil at the Norman E. Borlaug Crop Research Center, G.B. Pant University of Agriculture and Technology, Pantnagar, Udham Singh Nagar District, Uttarakhand during of 2021-22. Nine treatment combinations comprising weedy, weed free, pre-emergence (PE) application of atrazine 1.0 kg/ha followed by hand weeding, atrazine 0.75 kg/ha PE followed by Post Emergence (PoE) application of topramezone 25.2 g/ha, atrazine 0.75 kg/ha PE *fb* tembotrione 120 g/ha PoE, atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE, early PoE application of topramezone 25.2 g/ha + atrazine 0.75 kg/ha, and early PoE application of tembotrione 120 g/ha + atrazine 0.75 kg/ha. These treatment combinations were distributed among three replications in a randomized block design. The hybrid variety '*DKC 9144*' was sown with a spacing of 60 × 25 cm on 24 June 2021 and harvested on 12 October 2021. Pre-emergence herbicides were applied immediately after sowing the crop whereas post-emergence herbicides were applied at 30 days after sowing (DAS). A single tank mix application of herbicides was performed as an early post-emergence treatment at 15 DAS. In the weed-free treatment, manual weeding was conducted three times at 18, 30 and 42 DAS to control weeds. The herbicides were applied using a flat fan nozzle, with a spray volume of 500 l/ha. Observations on the weed flora were recorded at 50 DAS. Weed samples were collected using a quadrate of 1.0 m^2 area, dried in shade for 2-3 days, and subsequently in a hot air oven at 65 ± 5^0C until a constant weight was achieved. The dry weight of the weeds was measured using a digital balance and expressed in grams per square meter (g/ m^2). The data on the number and dry weight of weeds were subjected to a square root transformation. The biomass accumulation by the crop was determined after sun drying for 2-3 days followed by oven drying at 65 ± 5^0C temperature until a constant weight was achieved and grain yield was calculated at maturity from net plot area (5.4 m^2).

Effects on weeds

Eleusine indica L., *Digitaria sanguinalis* L., *Echinochloa colona* L. and *Eragrostis japonica* L. were dominant among grassy weeds. Broad-leaf weeds were *Phyllanthus niruri* L., *Commelina benghalensis* L., *Cucumis melo* L. and *Cleome viscosa* L.. *Cyperus rotundus* L. was the only sedge. *Eleusine indica* was the major dominating weed which infested the crop at almost all stages of the crop which accounted for 35.4 and 28.5 % of the total weed population in weedy crop at 40 DAS and at harvest, respectively (**Table 1**).

Weedy plot exhibited significantly maximum total weed density at 40 DAS (542.7/m^2). Weed density in

Table 1. Relative weed density in weedy crop at different crop growth stages

S. No.	Weed species	Relative weed density (%)	
		40 DAS	At harvest
1.	*Cyperus rotundus*	15.2	0.0
2.	*Eleusine indica*	35.4	33.3
3.	*Echinochloa colona*	27.0	28.0
4.	*Eragrostis japonica*	5.2	19.6
5.	*Digitaria sanguinalis*	7.6	11.9
6.	*Cleome viscosa*	1.7	3.6
7.	*Commelina benghalensis*	3.2	1.2
8.	*Cucumis melo*	1.7	0.6
9.	*Phyllanthus niruri*	2.9	1.8

weedy crop decreased with advancement of crop age (224.0/m^2 at harvest) owing to completion of life-cycle of weeds. At 40 DAS atrazine 1.0 kg/ha PE *fb* hand weeding) recorded significantly lowest total weed density. Both sequential (atrazine 0.75 kg/ha PE followed by Post Emergence (PoE) application of topramezone 25.2 g/ha, atrazine 0.75 kg/ha PE *fb* tembotrione 0120 g/ha PoE, atrazine1.0 kg/ha PE *fb* topramezone - 25.2 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE) and tank mix (early PoE application of topramezone 25.2 g/ha + atrazine 0.75 kg/ha, and early PoE application of tembotrione - 120 g/ha + atrazine 0.75 kg/ha) application had statistically equal total weed density. At harvest, atrazine 1.0 kg/ha PE *fb* hand weeding) recorded significantly lower weed density, which was at par with weedy check. tembotrione 120 g/ha + atrazine 0.75 kg/ha recorded significantly higher total weed density, which was at par with other sequential and tank mix treatments except in atrazine 0.75 kg/ha PE followed by Post Emergence (PoE) application of topramezone 25.2 g/ ha and atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha as PoE. Results showed that under tank mix treatments (included topramezone and tembotrione) applied as early post-emergence at 15 DAS had strong photo bleaching effects on shoots and reduced biosynthesis of carotenoids in early emerged weeds led to lower weed density.

Under weedy condition, uncontrolled weed growth resulted into the highest weed density. Weedy plot exhibited significantly higher total weed dry matter accumulation at respective crop growth stages (330.4 and 323.2 g/m^2, respectively).

At 40 DAS, all sequential treatments exhibited significantly more dry matter than tank mix treatments. At 50 DAS, all herbicidal treatments were statistically at par with the maximum value in atrazine 1.0 kg/ha PE *fb* topramezone - 25.2 g/ha PoE.. At harvest, all sequential and tank mix application were at par with each-other. However, pre-emergence (PE) application of atrazine 1.0 kg/ha followed by hand weeding recorded significantly more dry matter than other herbicidal treatments. The further germination of susceptible weed species was prevented under

Table 2. Effects of herbicide treatments on weeds crop growth and yield of maize

Treatment	Weed density (no./m^2)		Weed dry matter (g/m^2)		Crop biomass (g/plant)		Grain yield (t/ha)
	40 DAS	At harvest	40 DAS	At harvest	40 DAS	60 DAS	
Weedy	23.3(543)	14.9(224)	18.2(330)	17.9(323)	34.9	69.7	3.46
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	60.1	106.1	7.20
Atrazine -1 kg/ha PE *fb* HW	11.8(139)	14.8(219)	9.2(84)	14.0(196)	51.2	101.1	6.94
Atrazine -0.75 kg/ha PE *fb* topramezone 25.2 g/ha PoE	17.1(295)	16.6(278)	13.3(178)	10.5(110)	55.3	103.9	6.60
Atrazine -0.75 kg/ha PE *fb* tembotrione 120 g/ha PoE	17.0(291)	18.1(331)	13.2(175)	11.7(137)	52.5	102.9	6.65
Atrazine -1.0 kg/ha PE *fb* topramezone 25.2 g/ha PoE	17.4(304)	16.9(288)	13.9(193)	10.9(117)	57.8	106.0	6.67
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE	16.7(279)	18.8(357)	13.2(173)	11.1(125)	56.7	104.6	6.88
Topramezone 25.2 g/ha E-PoE + atrazine 0.75 kg/ha	16.1(263)	19.3(373)	11.9(142)	12.4(154)	59.6	105.0	6.42
Tembotrione 120 g/ha E-PoE + atrazine 0.75 kg/ha	15.9(253)	19.4(379)	11.7(137)	12.6(159)	54.9	107.1	6.50
LSD (p=0.05)	2.0	1.9	1.5	1.5	12.4	15.6	1.26

*Original values are given in the parentheses

herbicidal treatments which resulted in lesser population and thus lower total dry matter accumulation (Samant *et al.* 2015).

Effect on maize growth

At 40 DAS, weed free crop attained maximum dry matter accumulation (60.1 g/plant) which was at par with those grown under herbicidal treatments. Dry matter accumulation was significantly lowered by 42.0 and 41.5% in weedy plot in comparison to weed free treatment and in early PoE application of topramezone - 25.2 g/ha + atrazine 0.75 kg/ha treatment, respectively. The same results were found at 60 DAS where tembotrione 120 g/ha + atrazine 0.75 kg/ha Early PoE) being at par with all weed control treatments attained the highest dry matter accumulation which was more than weedy plot (**Table 2**). Weedy treatment had significantly lowest dry matter accumulation of crop. Results indicated that herbicide treatments effectively controlled the weeds due to their broad-spectrum nature. The lower weed density under herbicidal treatments resulted into reduced crop-weed competition and helped the crop to make efficient utilization of solar radiation, space, moisture and nutrients. More plant height and leaf area index resulted into higher dry matter accumulation in plants grown in herbicidal and weed free treatments (Swetha *et al.* 2018).

Effect on grain yield

The weed-free treatment achieved the highest grain yield, measuring 7.2 t/ha. This value was similar to the grain yield of all herbicide-treated crops and significantly higher than the grain yield of the weedy crop. Among the herbicide treatments, both sequential and tank mix applications showed similar results. The weedy crop had the lowest grain yield, measuring 3.4 t/ha, which was 51.9% lower than the yield of the weed-free crop. The sequential application of herbicides (atrazine 0.75 kg/ha PE followed by Post Emergence (PoE) application of topramezone 25.2 g/ha, atrazine 0.75 kg/ha PE *fb* tembotrione 120 g/ha PoE, atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE) resulted in significantly higher grain yields of 90.9%, 92.4%, 92.7% and 98.8%, respectively compared to the weedy treatment. Similarly, the tank mix application (early PoE application of topramezone 25.2 g/ha + atrazine 0.75 kg/ha and early PoE application of tembotrione 120 g/ha + atrazine 0.75 kg/ha) increased the grain yield by 85.5% and 88.1%, respectively compared to the weedy treatment (**Table 2**).

The findings suggested that tank mix application of atrazine at a reduced dosage of 0.75 kg/ha combined with either tembotrione at 120 g/ha or topramezone at 25.2 g/ha at 15 DAS as single application can be recommended as a cost effective method of weed control in maize.

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RESEARCH NOTE

Integrated weed management minimizing crop yield reduction in vegetable peas

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ABSTRACT

Research experiment was carried out at the ICAR-Indian Agricultural Research Institute (IARI), New Delhi, during the winter season of 2021-22 (28°382 N latitude, 77°102 E longitude; altitude 229 m above mean sea level) to study the effect of integrated weed management practices in vegetable pea. Randomized complete block design with three replications was used to set up eight treatments as detailed in methodology. Compared to conventional weed management practices, integrated weed management is a viable option for effective weed management in vegetable peas. Sequential application of pre- and post-emergence herbicides, in conjunction with other practices such as mulching and mechanical weeding, effectively reduces crop-weed competition at critical growth stages, giving the crop a competitive advantage to grow to its full potential, positively influencing biomass production and crop productivity and lesser reduction in crop yield. As a result, sequential application of pendimethalin as PE 750 g/ha *fb* mulch *fb* ready mix of (metribuzin + clodinafop) as PoE 270 g/ha may be recommended for effective weed control, profitability, and long-term sustainability of vegetable peas. Next option could be mechanical weeding, which suppresses weeds, reduces herbicide use, and improves soil aeration, better nutrient mineralization, better soil tilth, temperature regulation, and also improves the water holding capacity of the soil.

Keywords: Integrated weed management, Metribuzin + clodinafop, Vegetable peas, Weed control efficiency, Weed control index

Vegetable pea (*Pisum sativum* var. *hortense* L.) is an important Leguminosae family winter crop. It is consumed worldwide in both fresh and processed forms. It is thought to have originated in the Near East and the Mediterranean, and it has been cultivated since the early Neolithic period (Ambika *et al.* 2022). India outperforms all other countries in terms of vegetable pea production. Vegetable pea is commercially grown in Northern India's plains during the *Rabi* (winter) season, whereas it is successfully grown in hilly areas during the summer months because it requires a cool climate for optimal growth in the early stages, it is grown as a *Rabi* crop from the beginning of October till end of November. Its growth is more likely in areas with a smooth transition from cold to warm weather. Cultivation in India is limited to 5.49 lakh ha with a production of 56.8 lakh MT and a productivity of 10.34 MT/ha (1st Advance Estimate, 2021-22). In the Delhi foothills, vegetable pea is grown as a second crop after rainy season crops such as maize and paddy. Currently, there is a significant mismatch between potential and realized yield in the state's vegetable pea production. During 2020-2021, approximately 0.3 lakh hectares of vegetable pea was cultivated in Delhi, yielding 0.7 lakh tonnes and a productivity of 2333 kg/ha. Talking about its constituents, peas are high in protein, sugars, carbohydrates, minerals, vitamins A, B, and C, and essential amino acids. In addition, a large portion of peas are processed (canned, frozen, or dehydrated) for year-round consumption (Anonymus 2019-20). Because of its slow growth and wide spacing, it provides ample opportunity for weeds to grow during the early stages of its life cycle, resulting in acute crop-weed competition for water, nutrients, space, and sunlight, resulting in a 40-70% reduction in crop yield (Harker *et al.* 2009).

Herbicide weed control is becoming more important and effective due to its ease of use, timely and precise weed control, and more economical (Kulshrestha *et al.* 2000, Sen *et al.* 2021). In peas only one broad spectrum herbicide namely pendimethalin has been recommended and used as pre-emergence (after 2-3 days of sowing) since long and it is quite effective for controlling weeds upto 15-20 days but, what about the weeds coming after 20-25 days after sowing? Using only pre-emergence herbicides are insufficient to control a wide range of weeds present under field conditions. Therefore, integration of herbicides with some other cultural options like use of crop residues, mechanical/manual weeding may provide effective weed control (Kaur *et al.* 2020a and 2020b). The outlook for weed

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management improves when chemical weed control methods are integrated into systems that link cultural, mechanical, rotational, and biological methods. By integrating weed management options, we can reduce chemical load (residue) issues in soil, plants, and water. Keeping these facts in view, this experiment entitled "Comparing the effectiveness of integrated weed management techniques in controlling weeds and minimizing crop yield reduction in vegetable pea (*Pisum sativum* var. *hortense* L.)" was planned and executed with an objective to study the effect of integrated weed management strategies on crop growth, productivity and yield loss. In this paper, the effect of integrated weed management practices on weed control efficiency, weed control index and reduction in crop yield due to weed infestation has been discussed.

The field experiment was carried out at the ICAR-Indian Agricultural Research Institute (IARI), New Delhi, during the winter season of 2021-22 (28°382 N latitude, 77°102 E longitude; altitude 229 m above mean sea level). The climate at the site is semi-arid and subtropical, with hot and dry summers and cold winters. The soil at the study site was sandy loam, with a pH of 7.8, EC of 0.47 dSm^{-1} and OC of 0.41%. A randomized complete block design with three replications was used to set up eight treatments *viz a viz.* mulch followed by (*fb*) metribuzin 70% WP (100g/ha) as early post-emergence at 2-3 leaf stage, mulch *fb* quizalofop 5% EC (50 g/ha) as post-emergence at 30 DAS, mulch *fb* metribuzin + clodinafop (270 g/ha) as post-emergence at 30 DAS, pendimethalin 30% EC (750 g/ha) as pre-emergence at 2 DAS *fb* mulch *fb* quizalofop-p-ethyl 5% EC (37.5g/ha) as post-emergence at 30 DAS, pendimethalin 30% EC (750 g/ha) as pre-emergence at 2 DAS *fb* Mulch *fb* metribuzin + clodinafop (270 g/ ha) at 30 DAS, two mechanical weeding (Pusa Mini Electrical Prime Mower) at 25 and 50 DAS, weed-free check (WFC), where weeds were manually removed to keep the crop weed-free throughout the crop growth and unweeded control (UWC), where weeds were allowed to grow with crops throughout the crop growth. Air-dried maize residue (3 t/ha as applicable to treatments) was immediately retained on the soil surface as mulch. All herbicides were applied with a knapsack sprayer fitted with a flat fan nozzle using 500 L/ha water. Vegetable pea (cv. *Pusa Pragati*) was sown on 11^{th}, November 2021, using 80 kg seed/ha. The observations on weeds were taken with a 1 m^2 quadrat at 40, 70 days after sowing and at harvest. The data on weed density and dry matter production was analyzed using square root transformation as ($\sqrt{x+0.5}$) for uniformity in their distribution. The data on weed control efficiency (WCE), weed control index (WCI) and weed index (WI) was calculated using the following equations:

$$WCE\ (\%) = (WP_c – WP_t)/WP_c * 100 \quad (1)$$

where, WP_c and WP_t are weed density ($no.m^{-2}$) in UWC and treatment plots, respectively.

Weed control index (WCI), which reflects per cent reduction in weed dry weight by a treatment compared to UWC was determined using eq. 2.

$$WCI\ (\%) = (WD_c – WD_t)/WD_c * 100 \quad (2)$$

where, WD_c and WD_t are weed dry weights (g/m^2) in the UWC and treatment plots, respectively.

Weed index (WI) is a measure of the efficiency of particular treatment in terms of yield output compared with that in WFC. It reflects percent yield loss due to weeds in a treatment compared to WFC and was calculated using eq. 3.

$$WI\ (\%) = (Y_{wf} – Y_t)/Y_{wf} * 100 \quad (3)$$

where, Y_{wf} and Y_t are green pea yields in the WFC and treatment plots, respectively.

Weed interference and control efficiency

The major weed flora of the experimental site consists of a mixture of grassy, broad-leaved weeds and sedges (*Anagrallis arvensis*, *Chenopodium album*, *Chenopodium murale*, *Coronopus didymus*, *Fumaria parviflora*, *Medicago denticulata*, *Melilotus indica*, *Spergula arvensis*, *Avena ludoviciana*, *Cynodon dactylon*, *Phalaris minor*, *Asphodelus tenuifolius*, *Lolium temulentum* and *Cyperus rotundus*). The highest weed control efficiency (WCE) and weed control index (WCI) was obtained in weed free treatment, as this treatment was kept deliberately free from weeds throughout the crop growth period (**Table 1**). The highest WCE and WCI in this treatment was obtained because of zero competition between the crop and weeds. Among herbicidal treatments, application of pendimethalin fb mulch fb (metribuzin + clodinafop) recorded (60.58%) of WCE followed by mechanical weeding (58.39%) at harvest. Similarly, these two treatments were statistically at par in obtaining the WCI at harvest which was 62.2% with mechanical weeding and 60.4% with application of pendimethalin fb mulch *fb* (metribuzin + clodinafop) (**Table 1**). This could be attributed to the herbicide mixture's broad-spectrum activity and persistence, which reduced weed competition due to lower weed density and dry matter accumulation and was sustained throughout the crop growth period. Reduced crop-weed competition at critical growth stages increased the crop growth and made more space, nutrients, moisture, and light available. The findings of this study are consistent with the findings of another experiment, which discovered that an increase in seed yield could be attributed to effective weed control during the critical period of crop weed competition, which in turn reduced biotic stress (due to weed competition) and thus provided a weed-free environment. (moisture, nutrients, sunlight, *etc.*) for better growth and yield. (Kaur *et al.*). Remaining treatments recorded comparatively less WCE and WCI at all observational stages of the crop. The lowest WCE (33.20%) and WCI (32.09%) was reported in treatment where, mulch was applied followed by metribuzin at 100 g/ha as early post-emergence at 2-3 crop leaf stage.

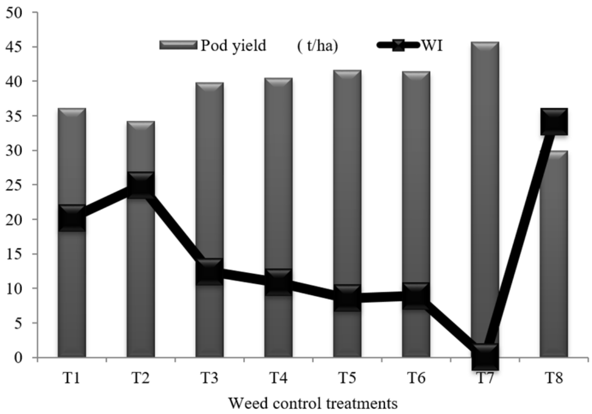
The plots treated with pendimethalin *fb* mulch *fb* quizalofop-p-ethyl, were able to provide good to excellent weed control. While pendimethalin is primarily a broad-leaf killer, quizalofop-p-ethyl herbicide is predominantly grass killer. It inhibits ACCase, a multifunctional, biotinylated protein found in plastid stroma that catalyses the ATP-dependent condensation of acetyl CoA and bicarbonate (HCO3-) to malonate in the fatty acid biosynthesis pathway (Liang Tong 2012). As a result, their integration has been shown to be more effective than most other treatments. In addition to this, inclusion of crop residues in the treatment further improved the WCE as well as WCI as weed seeds didn't get sufficient light and space to grow and compete with the crop.

Weed index

The weed index measures reduction in crop yield under different treatments due to presence of weeds in comparison to weed free plot. The reduction in yield ranged from 8.60 to as high as 34.12% because of the weed infestation observed under different weed control treatments (**Figure 1**). The reported yield loss was higher where application of only pre or post emergence herbicides was done. In the treatments where sequential application of herbicides along with retention of crop residue as mulch was done, reported less yield reduction. Pre-emergence application of pendimethalin *fb* mulch fb application of metribuzin + clodinafop had the lowest weed index (8.60%) or in other words we can say that reduction in yield in this treatment was less followed by mechanical weeding (8.94%). These two treatments were statistically at par with each other and significantly superior to rest of the treatments. Mechanical weeding (Pusa Mini Electrical Prime Mower at 25 and 50 DAS), showed promising results with lesser yield reduction and these results obtained may be because of better soil proliferation, uprooting of newly emerging weeds, better soil aeration and better root growth with mower at 25 and 50 DAS. Weeds compete with the crops for various growth factors like water, nutrients, space, light etc. and ultimately reduced the crop yield depending on the density and dry matter of weeds. In the treatments, where pre-emergence application of the herbicide was done, it controls the weeds which germinate along with the crop and post-emergence application of herbicide controls the second and afterward coming flushes of the weeds. So sequential application of herbicides reported less competition in these treatments compared to other treatments, resulting in lower yield reduction. In the weed free treatment (WFC, T_7), no reduction in yield was reported as no competition was there and this treatment was significantly superior to the rest of treatments studied. Contrary to this, unweeded control (T_8), where weeds were allowed to grow along with the crop and not a single weed control

Table 1. Weed control index (WCI) and Weed control efficiency (WCE) at 40, 70 days after sowing (DAS) and at harvest

Treatment	WCI (%)			WCE (%)		
	40 DAS	70 DAS	At harvest	40 DAS	70 DAS	At harvest
Mulch *fb* metribuzin 100g/ha EPoE at 2-3 leaf stage	31.41	33.70	33.20	36.66	38.63	32.09
Mulch *fb* quizalofop 50 g/ha PoE at 30 DAS	32.22	36.01	33.55	38.14	49.94	27.98
Mulch *fb* metribuzin + clodinafop 270 g/ha PoE at 30 DAS	47.47	51.68	45.46	47.04	59.38	44.65
Pendimethalin 750 g/ha PE at 2 DAS *fb* mulch *fb* quizalofop-p-ethyl 37.5g/ha PoE at 30 DAS	47.55	51.35	46.45	49.21	53.93	42.12
Pendimethalin 750 g/ha PE at 2 DAS *fb* Mulch *fb* metribuzin + clodinafop (270 g/ha) at 30 DAS	69.35	66.77	60.40	69.07	76.34	60.58
Two mechanical weedings (Pusa Mini Electrical Prime Mower) at 25 and 50 DAS	77.75	69.28	62.24	72.73	76.78	58.39
Weed-free check (WFC)	100.00	100.00	100.00	100.00	100.00	100.00
Unweeded control	0.00	0.00	0.00	0.00	0.00	0.00
LSD(p=0.05)	6.72	3.77	2.34	4.54	7.42	5.62



T_1- mulch *fb* metribuzin 100g/ha EPoE at 2-3 leaf stage, T_2- mulch *fb* quizalofop 50 g/ha PoE at 30 DAS, T_3- mulch *fb* metribuzin + clodinafop 270 g/ha PoE at 30 DAS, T_4- pendimethalin 750 g/ha PE at 2 DAS *fb* mulch *fb* quizalofop-p-ethyl 37.5g/ha PoE at 30 DAS, T_5- pendimethalin 750 g/ha PE at 2 DAS *fb* Mulch *fb* metribuzin + clodinafop (270 g/ha) at 30 DAS, T_6- two mechanical weedings (Pusa Mini Electrical Prime Mower) at 25 and 50 DAS, T_7- weed-free check (WFC) and T_8- unweeded control

Figure 1. Weed index (WI) showing vegetable pea yield losses across the various treatments

method was imposed for controlling weeds, recorded the maximum reduction in crop yield ranging to the tune of 34.12 % as seen in **Figure 1**. Weeds are more aggressive and competitive in nature; therefore, a significant reduction was noticed in this treatment and this treatment was significantly inferior to rest of the treatments.

Application of pre-emergence herbicide followed by (*fb*) post-emergence herbicides can improve broad-spectrum weed control, prevent weed shift, and delay resistance (Das *et al*. 2014, Kaur *et al*. 2020a). The plots treated with a combination of pre- and post-emergence application of herbicides as pendimethalin *fb* mulch *fb* quizalofop-p-ethyl was reported to provide good to excellent weed control. As a result, their integration has been shown promising results compared to other treatments. Our findings supported previous research results which found that integration of herbicides with some agro-practices, such as mechanical/manual weeding and crop residues, can selectively stimulate crop growth/ vigour and increase their competitiveness against weeds (Johnson and Holm 2010, Shalini and Singh 2014, Sen *et al.* 2020, Kaur *et al.* 2020a).

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RESEARCH NOTE

Bell pepper (*Capsicum annuum*) productivity and economics as influenced by different weed management strategies

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ABSTRACT

The effect of polythene mulches raised bed planting, and naphthalene acetic acid (NAA) application was evaluated for weed control, yield, and economics of bell pepper. The combination treatment of raised bed planting, plastic mulch and NAA recorded the lowest intensity of *Oxalis latifolia* (15%), *Amaranthus* spp. (4%), *Echinochloa crus-galli* (5 %), *Setaria* spp. (23%) and *Commelina benghalensis* (15%). The combination of raised bed planting, double-colored polythene mulch and NAA recorded the highest yield (38.9 t/ha). The combination of raised bed planting, black polythene mulch, and NAA had the lowest weed density (277 no/m^2), less weed dry biomass (119 g/m^2), and the highest weed control efficiency (66%).

Keywords: Bell Pepper, Weed Density, Weed Control Efficiency, Yield

Bell pepper (*Capsicum annuum* L.) is one of the most important vegetable crops. It belongs to the Solanaceae family and is a vegetable appreciated by consumers because of its pleasant, refreshing taste, attractive color, and special biochemical composition (Araceli Minerva *et al*. 2011). So, the demand for this vegetable is increasing very fast. Many challenges, such as biotic and abiotic stresses, have been known to reduce the quality and production of vegetable crops (Mennan *et al*. 2020). Weeds are one of the major biotic factors that harm production (Uljol *et al*. 2016). The weeds snatch up valuable and expensive inputs like nutrients and water that are otherwise intended for maximizing the potential yield and, also operate as alternative hosts for a variety of insect pests and diseases (Shehata *et al*. 2017). Uljol *et al*. (2016) reported that weeds cause 85 to 86 % fruit yield loss in bell peppers.

The crop productivity should be increased by developing an effective weed control strategy to limit the negative effects of weeds (El-Metwally *et al*. 2019). Manual weeding is costly, time-consuming, tedious, and causes root injury. In this context, plastic mulching and different planting techniques are good interventions to manage weeds. Mulch reduces weeds by acting as a physical barrier, which inhibits growth, and by its effect on shading, which inhibits weed germination and seedling growth (Rajablarijani *et al*. 2014). Plastic mulches directly impact the microclimate in the area around the plant, by altering the radiation budget and reducing soil water loss. Raised bed planting systems have several advantages, including water savings of up to 30% combined with improved water use efficiency, improvements in soil physical properties, nitrogen use efficiency, better sunlight utilization, low crop-weed completion, and ultimately an increase in crop yield (Kumar *et al*. 2010). Bahadur *et al*. (2013) reported that raised bed planting, had a greater reduction in weed biomass than flat-bed planting because in raised beds the water was only delivered in the furrows, and the surrounding region was usually dry, preventing significant weed development and less weed interference with crop growth boosts yield.

The limitations of bell pepper production in open field conditions, such as flower dropping, poor fruit set, and vulnerability to viral infections, pose a severe threat to the growth of this crop. However, growth regulators may be useful in reducing bell pepper dropping and may enhance the quantity, size, and weight of the fruit (Monir 2018). Akhter *et al*. (2018) observed that Naphthalene acetic acid is effective in increasing fruit set and is also used in reducing pre-harvest fruit drop resulting in a higher number of fruits and yield. Considering the above fact, the present experiment was done to evaluate the effect of planting methods, mulching, and NAA application on weed control and the economics of bell pepper.

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Table 1. Details of treatments used in the studies

Treatment no.	Treatment code	Treatment details
T_1	$P_1M_1N_1$	Raised bed + black polythene mulch + NAA application 15ppm at 30 and 45 days after transplanting
T_2	$P_1M_1N_2$	Raised bed + black polythene mulch + no NAA application
T_3	$P_1M_2N_1$	Raised bed + double colored (silver/black) polythene mulch + NAA application 15ppm at 30 and 45 days after transplanting
T_4	$P_1M_2N_2$	Raised bed + double colored (silver/black) polythene mulch + No NAA application
T_5	$P_1M_3N_1$	Raised bed + no mulch + NAA application 15ppm at 30 and 45 days after transplanting
T_6	$P_1M_3N_2$	Raised bed + no mulch + no NAA application
T_7	$P_2M_1N_1$	Flat-bed + black polythene mulch + NAA application 15ppm at 30 and 45 days after transplanting
T_8	$P_2M_1N_2$	Flat-bed + black polythene mulch + no NAA application
T_9	$P_2M_2N_1$	Flat-bed + double colored (silver/black) polythene mulch + NAA application 15ppm at 30 and 45 days after transplanting
T_{10}	$P_2M_2N_2$	Flat-bed + double colored (silver/black) polythene mulch + No NAA application
T_{11}	$P_2M_3N_1$	Flat-bed + no mulch + NAA application15ppm at 30 and 45 days after transplanting
T_{12}	$P_2M_3N_2$	Flat-bed + no mulch + no NAA application

The field trial was undertaken in *Kharif* (summer) 2018 at the Dr. Yashwant Singh Parmar University of Horticulture and Forestry's Vegetable Experimental Farm in Nauni, Solan (Himachal Pradesh), which is located at a height of 1270 meters above mean sea level (MSL), at 3505'N latitude and 77011'E longitude. *Solan Bharpur* was selected as the experimental bell pepper cultivar. The soil at the experimental location was a sandy loam with pH 6.6, organic carbon 6.43 mg/liter, available nitrogen 317.68 kg/ha, phosphorus 21.2 kg/ha, and potassium 160.0 kg/ha. Fertilizers and farmyard manure were applied by the recommended package of practices for bell pepper (RDF: 100 N: 75 P: 55 K kg/ha). The treatments consisted of the two planting methods (raised bed and flat-bed), three mulches (black polythene, silver/black polythene, and no mulch), and two growth regulation (NAA spray 15 ppm at 30 and 45 days after transplanting and no NAA application) (**Table 1**). These 12 treatment combinations were arranged in a factorial randomized block design with three replications. Each elevated bed had a 15 cm height and there was a 45-centimeter gap between each bed. Plots were covered with 50 (200-gauge thickness) mulches as per treatment combinations and mulches were applied one week before transplanting.

The cropping season rainfall was 752.5 mm which was received mostly in August (233.8 mm). The maximum mean temperature varied from 26.7 to 30.5°C and minimum from 13.2 to 20.4°C and the maximum relative humidity recorded was 82 % and the minimum was 44 %. At sampling time, a 1x1 m quadrate was randomly placed in each plot to evaluate weed density and dry weight of various weeds. Weed dry weight was recorded by drying the weeds at 70ºC in an oven for 48 h. Weed control efficiency (%) was determined as per the standard formula. Weed intensity (%) was calculated as a specific number of weeds (**Table 2**) to the total number of weeds present in the 1 m^2 area of each plot and calculated as per the standard formula. Analysis of variance (ANOVA) for the experiment was done as per the model suggested by Panse and Sukhatme (2000).

Table 2. Different weed species were observed in the experimental field

Monocot	Dicot	Sedges
Setaria spp.	*Echinochloa crus-galli*	*Cyperus rotundus L.*
Commelina benghalensis	*Oxalis latifolia*	
	Amarantus spp.	

Effect on weeds and yield of bell pepper

The combined effect of the planting technique + mulching + NAA was significant on weeds and crop yield parameters (**Table 3**). Raised bed + black polythene mulch + NAA application 15ppm at 30 and 45 days after transplanting (T_1) recorded the lowest weed density (277/m^2) and was at par with Raised bed + Black polythene mulch + No NAA application (T_2) (286.31/m^2), T_1 recorded the lowest dry biomass of weeds (119g/m^2) which was at par with T_2 (122g/m^2), T_8 (127g/m^2), and T_7 (131g/m^2), respectively. Flat bed with no mulch and no NAA (T_{12}) recorded higher weed dry biomass (349g/m^2). T_1 recorded the highest weed control efficiency (66%) which was at par with T_2 (65%), T_8 (63%), T_7 (62%), T_9 (55%), T_{10} (54%), T_3 (55%) and T_4 (54%), whereas, T_{11} gave the lowest weed control efficiency (10 %). Growing crops on raised beds is more efficient than conventional methods in reducing weed infestation and lodging and producing higher yields (Fahong *et al*. 2004). Treatments having black polythene mulch recorded a minimum number of weed density and biomass and higher weed control efficiency as the mulch material prevented germination of weed seeds (Ashrafuzzaman *et al.* 2011).

T_3 treatment having raised bed, silver/black polythene mulch and NAA recorded the highest crop yield (38.9 t/ha), while bare soil treatment (T_{12}) had the lowest (23.2 t/ha) yield. Raised bed planting improves soil organic matter and physical aspects due to surface retention of residues and reduces soil compaction by restricting traffic to the furrows (Govaerts *et al.* 2007). The color of plastic mulches and seasonal weather have a considerable impact on the pepper plant's fruit yield (Díaz-Pérez, 2010). This impact is associated with the impact of plastic mulching on the improvement of the microclimate and root zone temperature of plants which increases activities of cell expansion and cell enlargement. Furthermore, the active involvement of the enzymes in enhancing growth and development also increased crop yield (Li *et al.* 2004). The endogenous hormonal pattern of the plant is impacted by the exogenous application of growth regulators like naphthalene acetic acid, either by supplementing inadequate levels or by interacting with their synthesis, translocation, or inactivation of existing hormone levels, which increases crop yield (Singh *et al.* 2017).

Economics of bell pepper production

The highest gross income (₹ 5,83,0710/ha) was recorded under Raised bed + Double colored (silver/black) polythene mulch + NAA application 15 ppm at 30 and 45 days after transplanting (T_3) followed by Flat-bed + Double colored (silver/black) polythene mulch + NAA application 15ppm at 30 and 45 days after transplanting (T_9) (₹ 5,39,265/ha), whereas, it was lowest (₹ 3,48,150/ha) in T_{12}. On the other hand, T_3 had the highest cost of cultivation (₹ 2,35,560/ha) followed by T_9 (₹ 2,30,566/ha) and lowest in T_{12} (₹ 1,58,363/ha). The reason for increased net profit in treatment T_3 may be due to maximum marketable yield, healthy and better fruit size, and higher net returns as compared to other treatments which, however, recorded more B: C ratio like T_5 (1:53) and T_{11} (1:50) (**Table 3**). Dadeech *et al.* (2018) also recorded the highest net returns while using silver mulch in watermelon. The highest net returns of ^{1} 3,48,149/ha in T_3 may be attributed to less

Table 3. Effect of different treatments on weed characters, yield and economics of bell pepper

Treatment	Weed density (no./m^2)	Weeds dry biomass (g/m^2)	Weed control efficiency (%)	Yield (kg/plot)	Yield (t/ha)	*Gross return (x10^4 `/ha)	Net return (x10^4 `/ha)	B: C ratio
T_1 ($P_1M_1N_1$)	277.7±32.58^a	119.0±7.21^a	65.8 (54.20) ±2.72^a	50.8±2.75^b	35.85±1.94^b	23.02	30.75	1.34^b
T_2 ($P_1M_1N_2$)	286.0±31.00^a	121.7±14.57^a	64.6 (53.58) ±7.58^a	47.9±0.42^c	33.78±0.30^c	22.86	27.80	1.22^c
T_3 ($P_1M_2N_1$)	387.0±57.42^b	155.7±12.34^a	55.3 (48.03) ±3.55^a	55.2±0.87^a	38.91±0.62^a	23.56	34.81	1.48^a
T_4 ($P_1M_2N_2$)	400.0±74.05^b	159.7±10.69^a	54.1 (47.36) ±3.47^a	48.6±1.28^{bc}	34.27±0.91^{bc}	23.32	28.08	1.20^c
T_5 ($P_1M_3N_1$)	1063.3±52.62^c	271.3±29.37^b	21.36 (26.42) ±14.93^{bc}	39.8±0.87^e	28.05±0.62^e	16.61	25.46	1.53^a
T_6 ($P_1M_3N_2$)	1150.0±48.59^d	253.0±62.86^b	26.7 (27.15) ±23.10^b	36.0±0.87^f	25.38±0.62^f	16.43	21.61	1.32^b
T_7 ($P_2M_1N_1$)	321.0±6.56^{ab}	130.7±2.52^a	62.3 (52.16) ±3.42^a	50.0±1.11^{bc}	35.26±0.78^{bc}	22.49	30.40	1.35^b
T_8($P_2M_1N_2$)	323.3±13.65^{ab}	127.3±10.69^a	63.4 (52.78) ±3.47^a	44.0±0.48^d	31.01±0.34^d	22.32	24.21	1.08^d
T_9 ($P_2M_2N_1$)	368.3±16.44^{ab}	155.0±8.72^a	55.4 (48.10) ±3.97^a	51.0±1.59^b	35.95±1.12^b	23.06	30.87	1.34^b
T_{10} ($P_2M_2N_2$)	411.0±42.44^b	159.3±5.13^a	54.1 (47.37) ±3.51^a	45.2±2.11^d	31.90±1.49^d	22.82	25.03	1.10^d
T_{11} ($P_2M_3N_1$)	1219.3±107.64^d	313.0±10.58^c	9.9 (17.79) ±6.59^{cd}	37.9±0.97^{ef}	26.76±0.68^{ef}	16.03	24.11	1.50^a
T_{12}($P_2M_3N_2$)	1161.3±34.27^d	349.3±38.70^c	0.0 (0.00) ±0.00^d	32.9±0.24^g	23.21±0.17^g	15.84	19.00	1.20^c
LSD (p=0.05)	76.38	40.74	12.00	2.28	1.61	-	-	0.09

*Figures in parentheses represent angular transformation

*The gross returns were worked out based on the sale price of bell Pepper ₹ 15/-kg fixed by the University

P_1: Raised bed planting method, P_2: Flat-bed planting method, M_1: Black polythene mulch, M_2: Silver/black polythene mulch, M_3: No mulch, N_1: NAA application 15ppm at 30 and 45 days after transplanting, N_2: No NAA application

Table 4. Effect of different treatments on weed intensity (%)

Treatment	*Oxalis latifolia* (%)	*Amaranthus* spp. (%)	*Cyperus rotundus* (%)	*Echinochloa crus-galli* (%)	*Setaria* spp. (%)	*Commelina benghalensis* (%)
T_1 ($P_1M_1N_1$)	14.7(22.5) ±0.90^a	4.2(11.8) ±0.71^a	10.1(18.50) ±0.13^a	5.2(13.20) ±0.56^a	23.1(28.72) ±0.78^a	14.8(22.64) ±0.23^a
T_2 ($P_1M_1N_2$)	24.4(29.0) ±14.91^b	4.7(12.5) ±0.17^{ab}	10.0(18.5) ±0.34^a	5.8(13.9) ±0.23^a	23.6(29.1) ±0.62^a	15.1(22.9) ±0.39^a
T_3 ($P_1M_2N_1$)	24.9(29.9) ±0.56^b	6.9(15.2) ±0.30^d	15.3(23.0) ±0.67^c	7.2(15.5) ±0.62^b	26.2(30.8) ±1.02^b	17.4(24.6) ±0.99^{bc}
T_4 ($P_1M_2N_2$)	23.6(29.1) ±0.21^b	6.8(15.1) ±0.40^d	15.0(22.8) ±0.07^c	7.0(15.3) ±0.47^b	26.4(30.9) ±1.22^b	18.0(25.1) ±0.82^c
T_5 ($P_1M_3N_1$)	53.4(47.0) ±0.41^c	18.9(25.8) ±0.37^f	55.3(48.0) ±0.76^e	12.2(20.4) ±0.62^d	41.0(39.8) ±0.27^c	27.1(31.3) ±0.72^e
T_6 ($P_1M_3N_2$)	54.0(47.3) ±0.14^c	19.1(25.9) ±0.15^f	55.2(48.0) ±1.66^e	12.0(20.3) ±0.53^d	41.5(40.1) ±0.76^c	27.2(31.4) ±0.37^e
T_7 ($P_2M_1N_1$)	15.7(23.3) ±0.42^a	5.5(13.6) ±0.81^{bc}	12.8(21.0) ±0.68^b	5.8(14.0) ±0.19^a	24.2(29.4) ±0.99^a	16.6(24.0) ±0.24^b
T_8($P_2M_1N_2$)	14.9(22.7) ±0.94^a	6.0(14.1) ±0.49^{cd}	12.8(21.0) ±0.74^b	5.6(13.7) ±0.33^a	24.0(29.3) ±0.51^a	16.9(24.2) ±0.04^{bc}
T_9 ($P_2M_2N_1$)	28.2(32.1) ±0.59^b	9.4(17.8) ±0.48^e	21.8(27.8) ±1.38^d	8.2(16.6) ±0.35^c	26.6(31.1) ±0.54^b	19.9(26.5) ±0.55^d
T_{10} ($P_2M_2N_2$)	28.5(32.2) ±0.55^b	9.6(18.0) ±0.51^e	21.8(27.6) ±1.32^d	8.2(16.6) ±0.84^c	27.0(31.3) ±0.17^b	20.1(26.7) ±0.76^d
T_{11} ($P_2M_3N_1$)	63.5(52.8) ±1.98^d	21.4(27.6) ±0.90^g	63.0(52.2) ±0.72^f	13.8(21.8) ±0.44^e	47.5(43.6) ±0.76^d	32.5(34.7) ±0.76^f
T_{12}($P_2M_3N_2$)	63.3(52.7) ±0.17^d	21.5(27.6) ±0.96^g	63.3(52.3) ±0.74^f	13.8(21.8) ±0.27^e	47.9(43.8) ±0.17^d	32.5(34.7) ±1.01^f
LSD (p=0.05)	7.58	0.57	1.06	0.84	0.83	1.00

*Figures in parentheses represent angular transformation

P_1: Raised bed planting method, P_2: Flat-bed planting method, M_1: Black polythene mulch, M_2: Silver/black polythene mulch, M_3: No mulch, N_1: NAA application 15ppm at 30 and 45 days after transplanting, N_2: No NAA application expenditure on the labor involved in weeding, hoeing, and other cultural operations such as mulch-controlled weeds. Similar results on the effect of mulching on seed production of bell pepper have also been shown by Verma *et al*. (2014). Increased yield and, net returns by using raised bed technology have also been shown by Kumar *et al*. (2015) in garlic crops under irrigated conditions in Uttar Pradesh.

Effect on weed intensity (%)

A combination of planting techniques, mulching, and NAA spray showed significant results for weed intensity (**Table 4**). T_1 recorded lower intensity of *Oxalis latifolia* (14.7%) which was at par with T_8 (14.9%) and T_7 (15.7%) while higher was noted in T_{11} (63.50%). Similarly, lower weed intensity of *Amaranthus* spp. (4.2%), *Cyperus rotundus* (10%), *Echinochloa crus-galli* (5.2%), and *Setaria* spp. (23.1%) was observed in T_1 and higher in T_{12} *i.e*., (21.5%), (63.3%), (13.8%) and (47.9%), respectively. T_1 recorded less intensity of *Commelina benghalensis* (14.8%) as compared to T_{11} (32.5%). Significantly higher weed populations in the unmulched than mulched plots could be more weed seeds spread better weed growth in the absence of mulch (Negi 2015) and the preventive effect of mulch on light penetration that acted as a physical barrier affecting the growth of most of the annual and perennial weeds (Mukherjee *et al*. 2010).

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RESEARCH NOTE

Modelling rice-weed competition under transplanted ecosystem

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ABSTRACT

A field experiment was conducted in the summer of 2021 at the Crop Research Farm of the College of Post-Graduate Studies in Agricultural Sciences, Meghalaya, to determine the extent of yield loss in rice with different periods of weed interference. Twelve weed control timings were used to identify critical periods of weed competition in transplanted rice. Gompertz and Logistic equations were fitted to yield data in response to increasing periods of weed control and weed interference, respectively. The results showed that critical weed-free periods to achieve 95% of weed-free yield ranged from 11 – 57 days after transplanting. Grain yield obtained from a weed control period up to 60 days after transplanting and a weed competition period of 12 days after transplanting were statistically at par with the no-weed competition until harvest plot. Despite registering the highest yields, the plots that were kept weed-free till harvest were less profitable due to the incurred weeding costs. The identification of the critical crop-weed competition period will facilitate improved decision-making regarding the timing of weed control.

Keywords: Critical weed-free period, Growing Degree Days, Mathematical modelling, Transplanted rice, Weed control timing

Weeds are the visible but unspectacular pests, attendance of which may be formidable but effects might not. Despite all recompenses, weeds continue to remain notorious yield reducers that are, in many situations, economically more harmful than insects, fungi or other crop pests. Rice cultivation has always remained significant for food and livelihood security. It is estimated that the demand for rice in India will be 121.2 million tonnes by the year 2030, and 137.3 million tonnes by the year 2050 (Mohapatra *et al*. 2013). In Meghalaya, rice is cultivated in an area of 0.11 million hectares with a production of 0.304 million tonnes and productivity of 2740 kg/ha (DES, 2017-18). Weeds cause severe yield losses in rice (Hosoya and Sugiyama 2017) and seriously harm the ecology and the local economy when they are introduced (Sosa *et al.* 2017). Moreover, weeds vary spatially and temporally and swiftly adapt to new preventive and control tactics, making their control tricky (Sosnoskie *et al.* 2006). The critical period of weed interference and the critical weed-free period are two separately assessed crop-weed competition components that are employed to determine the critical period of crop-weed competition (CPCWC) (Tursun *et al.* 2016).

The field experiment was carried out in the summer of 2021 at the Agronomy farm of the College of Post Graduate Studies in Agricultural Sciences, Umiam, Ri-Bhoi, Meghalaya. It was laid out in a randomized block design with three replications. The treatments consisted of 12 weed control timings (WCT): weedy until 12, 24, 36, 48, and 60 days after transplanting (DAT) and crop harvest; and weed-free until 12, 24, 36, 48, and 60 DAT and crop harvest. The soil of the experimental field was sandy clay loam in texture, moderately acidic (pH 4.97) in nature, medium in available nitrogen (308.5 kg/ha), medium available phosphorus (18.2 kg/ha) and medium in available potassium (175.8 kg/ha). The paddy variety '*CAUS-122*' was used for the study. The recommended dose of NPK, *i.e.*, 80:60:40 kg/ha were applied. Weeds were removed by hand according to the treatments and at weekly intervals thereafter.

The Gompertz equation (Knezevic *et al.* 2002) was used to describe the effect of increasing duration of weed free period on yield:

$$y = y_0 + a \times \exp\left[-\exp\left(-\frac{x - x_0}{b}\right)\right]$$

Logistic equation (Smitchger *et al.* 2012) was used to describe the increasing duration of weed interference on yield:

$$y = y_0 + a/\left[1 + abs\left(\frac{x}{x_0}\right)^b\right]$$

where, y: Relative yield (% of season-long weed free yiel d); y_0: Lower limit; a: Upper limit; x_0: Days/

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GDD giving a 50% response between the upper and lower limit (inflection point); x: Number of days/ GDD calculated after crop emergence; b: Slope of the line at the inflection point (rate of change)

The analysis and interpretation of data was done using the Fisher's protected least significant difference test at $p<0.05$. SigmaPlot 12.5 was used to fit the curves for determining the critical period of crop-weed competition. From the fitted curves, critical periods for 95% of the maximum yield were determined.

Effect on yield attributes of rice

A synergistic effect was observed on the various yield attributes with decreasing duration of crop weed interference (**Table 1**). The maximum number of grains per panicle was reported from the plot kept weed-free until harvest (65.6), whereas, the lowest number of grains per panicle (42.1) was observed from the full-season weed competition plot. The treatments registered no significant difference on 1000-grain weight.

Effect on grain yield of rice

The weed-free set of plots recorded yields ranging from 2.07 to 4.01 t/ha, whereas, the weedy set of plots recorded yields ranging from 1.77 to 3.79 t/ha. Maximum grain yield (4.01 t/ha) was registered with no weed competition. But grain yield obtained from weed control period up to 60 DAT (3.91 t/ha) and a weed competition period of 12 DAT (3.79 t/ha) were found to be statistically at par with the weed-free in the harvest plot. The plot kept weedy throughout the growing period recorded a 56% reduced yield as compared to the plot which was kept weed-free throughout its growing period. Puddled transplanted rice production systems possess higher yield potential than direct-seeded rice (DSR), primarily owing to the protection from weeds during the early stages of growth (Choudhary *et al*. 2008).

The plot kept weed-free until harvest recorded the highest harvest index (41.24%), which was statistically at par with the plot kept weedy up to 12 DAT harvest and the plot kept weed-free up to 60 DAT. Conversely, the plot kept weedy throughout the growth season recorded the lowest harvest index (20.34%), however, it was statistically at par with the plot kept weedy up to 60 DAT and the plot kept weedy up to 12 DAT. This decline may be from a decrease in economic yield relative to the biological yield of rice.

Economics

The benefit: cost ratio differed across treatments. It was found that keeping the plots weed-free until 60 DAT gave statistically par profitability as the plots that were kept weed-free unti harvest (**Table 1**). Albeit with highest yields, the completely weed-free plot was not the most profitable due to the costs incurred in continuous weed removal. This reinforces the importance of realizing a critical period for weed management.

Estimation of rice yield loss and critical period for weed control

The Gompertz equation accounted for about 95%, whereas the logistic equation accounted for more than 60% of the variation in rice grain yield (**Table 2**).

Table 1. Rice yield and yield attributes as influenced by divergent weedy and weed-free regimes

Treatment	No. of grains/panicle	No. of panicles/m^2	Test weight (g)	Grain yield (t/ha)	Harvest index (%)	B:C ratio
Weedy up to 12 DAT	63.3ef	276.3e	26.63a	3.79f (5)	39.87e	1.11bc
Weedy up to 24 DAT	60.2ef	242.7cde	25.97a	3.33def (17)	34.84cde	1.05bc
Weedy up to 36 DAT	52.5cd	192.3abc	25.23a	2.64bcd (34)	27.45abc	0.91abc
Weedy up to 48 DAT	48.9bc	163.3ab	25.13a	2.20abc (45)	23.74ab	0.82ab
Weedy up to 60 DAT	45.2ab	140.7a	25.43a	1.96ab (51)	20.54a	0.74a
Weedy up till harvest	42.1a	129.0a	24.41a	1.77a (56)	20.34a	0.71a
Weed-free up till harvest	65.6f	292.3e	26.83a	4.01f	41.24e	1.17c
Weed-free up to 12 DAT	47.3abc	151.0ab	24.44a	2.07abc (48)	21.38a	0.83ab
Weed-free up to 24 DAT	49.9bc	181.0ab	24.90a	2.49abc (38)	26.83ab	0.90abc
Weed-free up to 36 DAT	58.4de	211.0bcd	25.13a	2.90cde (28)	31.45bcd	0.97abc
Weed-free up to 48 DAT	61.6ef	257.0de	25.78a	3.52ef (12)	36.31de	1.10bc
Weed-free up to 60 DAT	64.0ef	284.6e	26.73a	3.91f (2)	39.39e	1.20c
LSD (p=0.05)	6.09	58.19	2.39	1.32	7.34	0.27

*Within the same columns, means followed by different letters are significantly different at the 0.05 probability level, according to DMRT; Values in parenthesis showing per cent decrease in grain yield over the plot kept weed-free until harvest

Table 2. Parameter estimates for the four-parameter Gompertz and Logistic model fitted to Rice grain yield (% of weed-free yield) in 2021 with their respective R^2 values

Treatment	Regression parametes				R^2
	b	y_0	A	x_0	
Weedy[a] (Based on DAT)	2.67	37.16	62.10	34.35	0.9992
Weed-free[b] (Based on DAT)	34.97	39.20	100.17	38.15	0.9988
Weedy[a] (Based on GDD)	2.79	38.39	60.86	419.89	0.9991
Weed-free[b] (Based on GDD)	403.67	40.16	94.92	461.49	0.9991

b: the slope of the line at the inflection point; y_0: the lower limit; a: the upper limit; x_0: the growing degree days giving a 50% response between the upper and the lower limit; R^2: Regression coefficient; [a:] Logistic equation; [b:] Gompertz equation

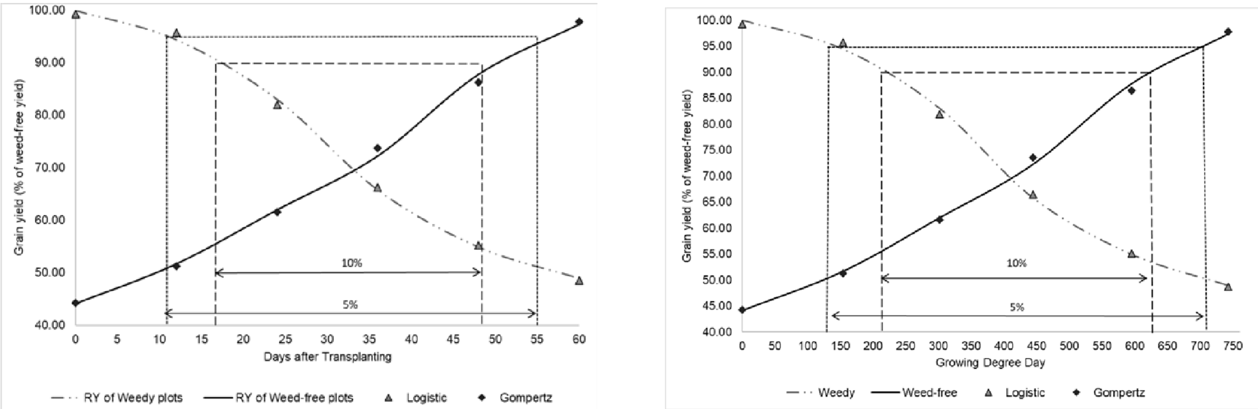

Figure 1. Critical period of rice-weed competition (a) DAT basis, (b) GDD basis

AYL (%)	CPCWC		
	DAT	GDD	CGS
Onset of the CPCWC			
5	11	140	First tillering stage
10	17	217	Active tillering stage
Culmination of the CPCWC			
5	57	704	Booting stage
10	50	620	Heading stage

Table 3. CPCWC in rice in Ri-Bhoi, Meghalaya in 2021 expressed in GDD, DAT and corresponding crop growth stage (CGS)

Based on the 5% acceptable yield loss (AYL), the onset of the CPCWC in rice was 140 GDD, suggesting the initiation of weed control at 11 DAT (**Figure 1a**), in accordance with the Logistic equation. Similarly, the end of CPCWC in rice was 704 GDD (**Figure 1b**), which corresponded to 57 DAT, as simulated by the Gompertz equation (**Table 3**). Based on the 10% AYL, the onset of the CPCWC in rice was 217 GDD, *i.e*., 17 DAT and the end of CPCWC in rice was 620 GDD, which corresponded to 50 DAT.

Thus, it may be concluded that weeds must be controlled within the period of 11 to 57 DAT and 17 to 50 DAT in rice to avoid 5 and 10% grain yield losses, respectively. The results of this study also dispense guidelines to rice growers for making decisions with respect to the weed competition period during which it is of economic importance to execute weed control measures in rice.

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