Indian Journal of Weed Science

Print ISSN 0253-8040
Online ISSN 0974-8164

Volume – 53 | Number – 2
April – June, 2021

Available Online @ www.indianjournals.com

Indian Society of Weed Science

ICAR-Directorate of Weed Research
Jabalpur - 482004, India
Website: www.isws.org.in

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Indian Journal of
Weed Science

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Indian Journal of Weed Science **53**(2): 117–122, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Indian Journal of Weed Science

Weed management in wet (drum)-seeded rice under Southern dry zone of Karnataka

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Article information

DOI: 10.5958/0974-8164.2021.00022.8

Type of article: Research article

Received : 16 March 2021
Revised : 24 May 2021
Accepted : 27 May 2021

Key words

Bispyribac-sodium, Economics, Sequential application, Weeds, Wet (drum)-seeded rice

ABSTRACT

A field experiment was conducted during *Kharif* (rainy season) 2014 and 2015 at Zonal Agricultural Research Station, V.C. Farm, Mandya, to identify suitable weed management practices for wet (drum)-seeded rice under Southern dry zone of Karnataka. Among the various treatments, pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR10 kg/ha *fb* post-emergence application of bispyribac sodium 25 g/ha at 20 days after sowing (DAS) being on par with weed free check, recorded significantly higher net monetary returns and B: C ratio. Uncontrolled weed growth caused 48.23-50.0% reduction in grain yield of wet (drum)-seeded rice.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important global food grain crops. In India, rice is contributing 45% to the total food grain production and is grown in an area of 44.1 million ha with a production of 106.64 million tonnes and productivity of 2.42 t/ha (Bhatt *et al.* 2017). Among several reasons for low rice productivity, the losses due to weeds are one of the most important. Herbicides are used to control weeds in crop as pre- or post-emergence application which reduce the population of weeds significantly resulting in higher yield and profit (Mishra *et al.* 2016).

In recent years, rice (*Oryza sativa* L.) production systems are undergoing several changes and one of such changes is shifting from transplanted rice to direct-seeded rice due to increased cos and non availability of labour during peak periods of agricultural operations. Sowing of sprouted rice seeds in wet puddled soils (wet-seeded rice) offers an alternative and labour-saving technique for stand establishment to the traditional transplanting. Wet-seeded rice is gaining momentum in India and it have the advantages of quick and easier planting, reduces labour requirement and increased water use efficiency. However, direct-seeded rice (DSR) is associated with several constraints like heavy weed infestation, water management immediately after sowing and lack of perfect leveling *etc*. Among them, heavy infestation of heterogenous weed flora becomes the biggest biological constraint as rice and weed seeds germinate simultaneously. The yield loss due to unchecked weed growth was reported up to 30-48% in DSR (Naseeruddin and Subramanyam 2013). The success of DSR is mainly depends on better weed management practices. Several studies indicated that, alone application of either pre-/post-emergence herbicides were not effective in seasonal long control of weeds (Dibyendu *et al.* 2019). Under such situation, sequential application of pre- and post emergence herbicide is a better option. Hence, the present investigation was carried out to identify suitable weed management practices for wet (drum)-seeded rice under Southern dry zone of Karnataka.

MATERIALS AND METHODS

A field experiment was conducted during *Kharif* (rainy season) 2014 and 2015 to identify suitable weed management practice for wet (drum)-seeded rice under Southern dry zone of Karnataka. The field study was conducted at Zonal Agricultural Research Station, V. C. Farm, Mandya ($12^0 34.3'$ N latitude, $76^0 49.8'$ E longitude and at an elevation of 697 m above mean sea level), of University of Agricultural

Sciences, Bengaluru. The soil of experimental site was red sandy loams with bulk density and particle density of 1.15 and 2.65 g/cc, respectively. The soil pH was 6.5 (neutral in reaction). It was low in available nitrogen and phosphorus and high in potassium. Eight treatments, *viz.* pyrazosulfuron-ethyl 25 g/ha as pre-emergence application (PE) + passing of one conoweeder at 40 DAS, bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) + passing of one conoweeder at 40 DAS, pyrazosulfuron-ethyl 25 g/ha (PE) + bispyribac-sodium 25 g/ha (30 DAS) as post-emergence application (PoE), bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) + bispyribac-sodium 25 g/ha (30 DAS) as PoE, bispyribac-sodium 25 g/ha as early post-emergence application (early post – 15 DAS). These weed control treatments were compared with hand weeding thrice at 20, 40 and 60 DAS, weedy and weed free check. These eight treatments were laid out in complete randomized block design with three replications.

Sowing of pre-germinated seeds of medium duration rice variety '*MTU-1001*' was done through 8 row drum seeders with a row to row spacing of 20 cm on well puddled and leveled field in June 2014 and 2015 with a seed rate of 62.5 kg/ha. The crop was fertilized with 100:50:50 kg N: P: K/ha and 50% nitrogen, entire dose of phosphorous and potassium was applied as basal in addition to zinc sulphate 25 kg/ha. The remaining 50% of the nitrogen was top dressed at two equal splits at tillering and panicle initiation stage. The gross plot size was 5.0 x 3.0 m. Pre-emergence herbicides were mixed with sand 100 kg/ha and applied uniformly in the field on 5 DAS. A thin film of water was maintained at the time of pre-emergence herbicide application. The post-emergence herbicides were sprayed at 3-4 leaf stage of weeds at 30 DAS by using knap-sack sprayer fitted with deflector nozzle mixed with water 750 liter/ha. Mechanical weeding with two row cono-weeder was carried out at 40 DAS as per the treatments. Hand weeding was carried out as per the treatment schedule. All other agronomic and plant protection measures were adopted as per the recommended packages of University of Agriculture Science (UAS), Bangalore. Bensulfuron-methyl 0.6% + pretilachlor 6% GR is combination of two herbicides and is in granular form and found safe to rice.

The efficacy of herbicides was tested by taking the observation on category wise weeds *viz.* grasses, sedges and broad-leaved weeds, weed density and biomass at 30 and 60 days after treatment of the crop by using a quadrate (0.5 x 0.5 m) randomly in each plot and their subsequent effect on growth and yield of wet (drum)-seeded rice. The weeds were uprooted from one m^2 area selected at random and were oven dried to a constant weight at 65°C and dry weight of weeds in each treatment was recorded and expressed as g per square meter. Data on growth parameters like plant height (cm) and number of tillers at harvest and yield parameters like grain weight per panicle (g), 100-seed weight (g), per cent choppiness and yield (kg/plot) of wet (drum)-seeded rice was recorded at harvest. The per cent choppiness was worked out by using the following formula.

$$\text{Per cent Choppiness} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

The data collected from the experiment at different growth stages were subjected to statistical analysis as described by Panse and Sukhatme (1967). The normality of distribution was not seen in case of observation on weeds hence, the values were subjected to square root transformation ($\sqrt{x+0.5}$) prior to statistical analysis to normalize their distribution. Statistical analysis was carried out based on mean values obtained. The level of significance used in 'F' and 't' test was P= 0.05. Critical difference values were calculated wherever 'F' test was significant as per the procedure given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed flora

The extent of growth and yield loss caused by weeds depends on weed species and their density in a crop community. Major weed flora observed in the experimental field in association with the wet (drum)-seeded rice, *viz. Eclipta alba* (false daisy) (16.2%), *Echinochloa colonum* L. (barnyard grass) (10.6%), *Echinochloa crus-galli* L. (barnyard grass) (3.5%), *Digitaria sanguinalis* L. (large crab grass) (3.2%), *Cynodon dactylon* (bermuda grass) (2.8%) and *Panicum repens* L. (quack grass) (1.2%) among grasses; *Ludwigia parviflora* (water primerose) (19.5%), *Ammannia baccifera* (blistering ammannia) (14.2%), *Commelina Benghalensis* L. (benghal dayflower) (8.0%), *Cyanotis cristata* (L.) (creseted dew grass) (3.2%), *Oxalis corniculata* L. (wood sorrel) (2.8%), *Marsilea quadrifolia* (water clover) (2.4%) among broad-leaved weeds (BLW); and *Cyperus rotundus* L. (purple nut sedge) (8.2%) and *Cyperus iria* L. (rice flat sedge) (4.2%) among sedges.

Weed density and biomass

All the weed control treatments significantly reduced the density and biomass of grasses, BLW, sedges and total weeds as compared to unweeded check **(Table 1, 2, 3** and **4)**. Among different category of weeds, density and biomass of broad-leaved weeds was higher in weedy check followed by grasses and sedges at 30 and 60 DAS in weedy check. Among the weed control treatments, hand weeding thrice at 20, 40 and 60 DAS recorded significantly lower weed density and biomass in both the years as compared to other treatments. However, it was at par with bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha PE *fb* bispyribac-sodium 25 g/ha PoE, pyrazosulfuron-ethyl 25 g/ha *fb* bispyribac-sodium 25 g/ha PoE and bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha PE + one conoweeder at 40 DAS also reduced the weed density and biomass as compared to application of pyrazosulfuron-ethyl 25 g/ha + conoweeder (40 DAS) and bispyribac-sodium 25 g/ha alone. However, all these treatments significantly lowered the weed density as compared to weedy check. Effective control of weeds with combination of

Table 1. Weed density (no./m^2) as influenced by weed management treatments in wet (drum)-seeded rice at 30 DAS

Treatment	Grasses		BLW		Sedges		Total	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl 25 g/ha (PE) + passing of one conoweeder at 40 DAS	2.46 (5.57)	2.53 (5.94)	3.85 (14.5)	3.95 (15.4)	1.72 (2.47)	1.83 (2.93)	4.79 (22.5)	4.96 (24.2)
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE) + passing of one conoweeder at 40 DAS	2.23 (4.47)	2.31 (4.90)	3.26 (10.1)	3.34 (10.7)	1.69 (2.36)	1.78 (2.69)	4.00 (15.5)	4.33 (18.3)
Pyrazosulfuron-ethyl 25 g/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	2.76 (7.10)	2.81 (7.41)	3.87 (14.5)	3.91 (14.8)	1.72 (2.45)	1.94 (3.28)	4.17 (16.9)	5.09 (25.5)
Bensulfuron methyl + pretilachlor 10 kg/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	2.19 (4.33)	2.30 (4.89)	3.26 (10.1)	3.32 (10.6)	1.65 (2.26)	1.99 (3.61)	3.57 (12.3)	4.42 (19.1)
Bispyribac-sodium 25 g/ha (early post) (15 DAS)	4.82 (22.8)	4.88 (23.4)	5.81 (33.3)	5.94 (34.8)	2.72 (6.91)	2.83 (7.55)	7.65 (58.0)	8.14 (65.8)
Hand weeding thrice at 20, 40 and 60 DAS	2.00 (3.52)	2.18 (4.26)	3.07 (8.9)	3.21 (9.9)	1.28 (1.14)	1.30 (1.18)	3.51 (11.9)	3.97 (15.3)
Weed free check (6 hand weeding)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.00)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)
Weedy check	6.04 (36.0)	6.29 (39.1)	8.12 (65.9)	8.31 (69.2)	3.11 (9.24)	3.57 (12.4)	10.19 (103.5)	10.99 (120.7)
LSD (p=0.05)	0.35	0.48	0.60	0.83	0.28	0.48	0.44	0.64

Square root $\sqrt{x+0.5}$ transformed values. Values in the parentheses are original values

Table 2. Weed density (no./m^2) as influenced by weed management treatments in wet (drum)-seeded rice at 60 DAS during 2014 and 2015

Treatment	Grasses		BLW		Sedges		Total	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl 25 g/ha (PE) + passing of one conoweeder at 40 DAS	3.97 (15.54)	4.05 (16.18)	3.98 (15.34)	4.00 (15.55)	1.68 (2.31)	1.78 (2.71)	5.79 (33.2)	5.90 (34.4)
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE) + passing of one conoweeder at 40 DAS	3.08 (9.02)	3.19 (9.73)	3.73 (13.49)	3.80 (14.10)	1.51 (1.80)	1.55 (1.95)	4.98 (24.3)	5.12 (25.8)
Pyrazosulfuron-ethyl 25 g/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	3.94 (15.06)	4.00 (15.58)	3.83 (14.20)	3.88 (14.59)	1.64 (2.19)	1.70 (2.38)	5.65 (31.5)	5.74 (32.6)
Bensulfuron methyl + pretilachlor 10 kg/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	2.95 (8.23)	2.98 (8.46)	3.72 (13.38)	3.80 (13.93)	1.50 (1.75)	1.55 (1.92)	4.88 (23.4)	4.98 (24.3)
Bispyribac-sodium 25 g/ha (early post) (15 DAS)	5.26 (27.16)	5.34 (28.17)	6.07 (36.39)	6.11 (36.87)	2.45 (5.58)	2.55 (6.16)	8.34 (69.1)	8.47 (71.2)
Hand weeding thrice at 20, 40 and 60 DAS	2.88 (7.81)	2.93 (8.13)	3.48 (11.65)	3.54 (12.05)	1.40 (1.45)	2.29 (6.40)	4.62 (20.9)	5.15 (26.6)
Weed free check (6 hand weeding)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Weedy check	6.72 (44.79)	6.80 (45.97)	8.66 (74.41)	8.71 (75.39)	2.93 (8.10)	2.99 (8.50)	11.30 (127.3)	11.41 (129.9)
LSD (p=0.05)	0.58	0.76	0.34	0.47	0.25	1.04	0.45	0.74

Square root $\sqrt{x+0.5}$ transformed values. Values in the parentheses are original values bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha *fb* bispyribac sodium 25 g/ha PoE was noticed at 30 and 60 DAS as evident from the reduced weed density and biomass. These findings were in conformity to Sangeetha (2006) and Dhanapal *et al.* (2018a). The crop yield is directly proportional to weed control efficiency. The weed control efficiency was maximum in hand weeding thrice at 20, 40 and 60 DAS (87.1% and 85.1% at 30 DAS and 83.5% and 82.1% at 60 DAS in 2014 and 2015, respectively) and bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha PE *fb* post-emergence application of bispyribac-sodium 25 g/ha PoE was best treatment among the herbicides in terms of higher WCE (87.1% and 86.0% at 30 DAS and 79.4% and 77.9% at 60 DAS in 2014 and 2015, respectively). These results were in agreement with (Pratik and Manoj 2017).

Growth, yield and yield attributes

All the herbicide treatments produced significantly higher grain yield compared to weedy check. Unweeded check registered 48.23% during 2014 and 50.0% during 2015 reduction in grain yield as compared to weed free check owing to sever competition offered by uncontrolled weeds for nutrients, soil moisture, space and light. Among the

Table 3. Weed biomass (g/m^2) as influenced by weed management treatments in wet (drum)-seeded rice at 30 DAS

Treatment	Grasses		BLW		Sedges		Total		Treatment	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl 25 g/ha (PE) + passing of one conoweeder at 40 DAS	1.44 (1.63)	1.53 (1.97)	1.24 (1.04)	1.26 (1.08)	1.35 (1.33)	1.39 (1.44)	2.12 (4.00)	2.22 (4.49)	78.8	77.1
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE) + passing of one conoweeder at 40 DAS	1.38 (1.42)	1.49 (1.83)	1.22 (0.98)	1.31 (1.24)	1.51 (1.81)	1.60 (2.12)	2.17 (4.22)	2.38 (5.19)	77.5	73.4
Pyrazosulfuron-ethyl 25 g/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	1.45 (1.62)	1.51 (1.84)	1.20 (0.95)	1.30 (1.23)	0.97 (0.45)	1.00 (0.49)	1.87 (3.01)	2.01 (3.56)	83.9	81.6
Bensulfuron methyl + pretilachlor 10 kg/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	1.31 (1.22)	1.36 (1.37)	1.06 (0.63)	1.09 (0.71)	1.03 (0.57)	1.07 (0.65)	1.71 (2.41)	1.79 (2.73)	87.1	86.0
Bispyribac-sodium 25 g/ha (early post) (15 DAS)	2.36 (5.10)	2.43 (5.43)	1.85 (2.95)	1.93 (3.29)	1.56 (2.11)	1.64 (2.43)	3.25 (10.15)	3.40 (11.15)	46.0	42.9
Hand weeding thrice at 20, 40 and 60 DAS	1.41 (1.48)	1.50 (1.77)	0.92 (0.35)	0.97 (0.46)	1.04 (0.59)	1.08 (0.66)	1.71 (2.41)	1.84 (2.90)	87.1	85.1
Weed free check (6 hand weeding)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	100.0	100.0
Weedy check	2.88 (7.81)	2.90 (7.95)	2.71 (6.85)	2.79 (7.35)	2.15 (4.14)	2.20 (4.36)	4.39 (18.79)	4.49 (19.66)	0.0	0.0
LSD (p=0.05)	0.29	0.46	0.18	0.33	0.37	0.47	0.27	0.37	-	-

Square root $\sqrt{x+0.5}$ transformed values. Values in the parentheses are original values

Table 4. Weed biomass (g/m^2) as influenced by weed management treatments in wet (drum)-seeded rice at 60 DAS

Treatment	Grasses		BLW		Sedges		Total		Treatment	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl 25 g/ha (PE) + passing of one conoweeder at 40 DAS	1.72 (2.46)	1.83 (2.91)	1.94 (3.27)	2.05 (3.72)	1.71 (2.44)	1.75 (2.59)	2.94 (8.17)	3.10 (9.23)	74.9	72.5
Bensulfuron-methyl + pretilachlor kg/ha (PE) + passing of one conoweeder at 40 DAS	1.67 (2.32)	1.75 (2.62)	1.88 (3.06)	1.94 (3.29)	1.75 (2.58)	1.83 (2.87)	2.91 (7.96)	3.04 (8.79)	75.3	73.6
Pyrazosulfuron-ethyl 25 g/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	1.79 (2.75)	1.87 (3.09)	1.86 (2.95)	1.93 (3.24)	1.40 (1.46)	1.46 (1.64)	2.77 (7.16)	2.91 (7.97)	77.9	76.4
Bensulfuron methyl + pretilachlor 10 kg/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	1.71 (2.44)	1.78 (2.72)	1.77 (2.67)	1.84 (2.96)	1.43 (1.54)	1.47 (1.67)	2.67 (6.65)	2.78 (7.35)	79.4	77.9
Bispyribac-sodium 25 g/ha (early post) (15 DAS)	2.47 (5.64)	2.54 (6.02)	3.03 (8.89)	3.08 (9.26)	2.28 (4.72)	2.35 (5.07)	4.44 (19.25)	4.56 (20.35)	41.1	40.6
Hand weeding thrice at 20, 40 and 60 DAS	1.55 (1.91)	1.62 (2.17)	1.37 (1.38)	1.41 (1.50)	1.60 (2.06)	1.71 (2.47)	2.42 (5.36)	2.57 (6.14)	83.5	82.1
Weed free check (6 hand weeding)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	100.0	100.0
Weedy check	3.37 (10.85)	3.51 (11.92)	3.66 (12.93)	3.71 (13.39)	3.08 (9.00)	3.18 (9.71)	5.76 (32.78)	5.94 (35.02)	0.0	0.0
LSD (p=0.05)	0.26	0.51	0.43	0.56	0.20	0.37	0.37	0.65	-	-

Square root $\sqrt{x+0.5}$ transformed values. Values in the parentheses are original values weed control treatments, significantly higher grain yield (5.62 and 5.50 t/ha in 2014 and 2015, respectively) was obtained with season long weed free check as compared to weedy check (**Table 6**). However, it was on par with pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha PE *fb* post-emergence application of bispyribac-sodium 25 g /ha PoE (5.24 and 4.90 t/ha in 2014 and 2015, respectively) and hand weeding thrice at 20, 40 and 60 DAS (5.39 and 4.98 t/ha in 2014 and 2015, respectively). The superior performance of these treatments was mainly attributed to enhanced yield parameters, *viz.* number of tillers/plants, grain weight/panicle and 100 seed weight **(Table 5).** The increase in rice grain yield over weedy check due to different treatments was attributed to the reduced density and biomass of weeds at all stages of crop growth, which resulted in increased dry matter of rice and number of panicles/ m^2. These results were in accordance with Sangeetha (2006), Dhanapal *et al*. (2018a) and Singh and Pairka (2014).

Economics

Among different weed management practice, the higher net returns (₹ 47,800 in 2014 and 43,935/ ha in 2015) and B:C (2.55 and 2.48 in 2014 and 2015, respectively) was recorded with bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha PE *fb* bispyribac-sodium 25 g/ha PoE. While, the lowest net returns (₹ 18,635 and 16,295 /ha in 2014 and 2015, respectively) and B:C (1.75 and 1.65 in 2014 and 2015, respectively) was observed in un weeded check **(Table 6)**. The increased monetary benefits in

Table 5. Growth and yield parameters of wet (drum)-seeded rice as influenced by weed management treatments

Treatment	Plant height at harvest (cm)		No. of tillers at harvest		Grain weight/ panicle (g)		100-seed weight (g)		Percent choppiness	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl 25 g/ha (PE) + passing of one conoweeder at 40 DAS	48.37	47.91	14.82	13.62	1.75	1.66	1.22	1.15	25.43	26.76
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE) + passing of one conoweeder at 40 DAS	51.21	50.24	14.98	13.88	2.78	2.67	1.57	1.52	17.85	18.78
Pyrazosulfuron-ethyl 25 g/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	51.97	51.28	15.18	13.87	2.78	2.67	1.58	1.50	17.71	19.24
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	52.59	51.56	15.32	14.04	2.85	2.70	1.77	1.61	14.99	16.31
Bispyribac-sodium 25 g/ha (early post) (15 DAS)	40.90	40.50	13.12	12.33	1.67	1.52	1.16	1.14	28.23	30.38
Hand weeding thrice at 20, 40 and 60 DAS	54.29	53.51	15.82	15.21	2.64	2.54	1.82	1.74	12.21	12.77
Weed free check (6 hand weeding)	56.60	55.77	17.11	15.99	2.66	2.54	1.84	1.72	10.82	11.88
Weedy check	37.77	37.09	10.38	9.57	1.51	1.44	1.12	1.10	56.66	58.82
LSD (p=0.05)	5.65	5.74	1.95	1.84	0.17	0.38	0.19	0.30	4.49	7.00

Table 6. Yield and economics of wet (drum)-seeded rice as influenced by weed management treatments.

Treatment	Grain yield (t/ha)		Weed Index (%)		Net returns (Rs./ha)		B:C ratio	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl 25 g/ha (PE) + passing of one conoweeder at 40 DAS	5.13	4.86	8.53	11.54	47195	43140	2.58	2.45
Bensulfuron-methyl + pretilachlor 10 kg/ha (PE) + passing of one conoweeder at 40 DAS	5.16	5.05	8.22	8.38	40430	38735	2.09	2.05
Pyrazosulfuron-ethyl (PE) + bispyribac-sodium 25+25 g/ha (PoE) (30 DAS)	5.20	4.87	7.42	11.50	48330	43235	2.63	2.45
Bensulfuron methyl + pretilachlor 10 kg/ha (PE) + bispyribac-sodium 25 g/ha (PoE) (30 DAS)	5.24	4.90	6.61	10.55	47800	43935	2.55	2.48
Bispyribac-sodium 25 g/ha (early post) (15 DAS)	3.04	2.92	45.95	46.93	18640	16930	1.69	1.63
Hand weeding thrice at 20, 40 and 60 DAS	5.39	4.98	3.99	9.53	51255	43900	2.73	2.42
Weed free check (6 hand weeding)	5.62	5.51	0.00	0.00	41300	39605	1.96	1.92
Weedy check	2.91	2.75	48.16	49.91	18635	16295	1.75	1.65
LSD (p=0.05)	0.40	0.71	6.96	12.78	-	-	-	-

this treatment were mainly attributed to higher grain yield and reduced labour cost. This result was obtained due to effective weed management at critical stages by integration of effective pre- and post-emergence herbicides along with manual weeding, which resulted in higher grain with reduced cost of cultivation. Similar findings have also been reported by Prameela *et al*. 2014 and Dhanapal *et al.* 2018b. Similar results of higher net returns and B:C ratio in direct seeded rice due to sequential application of herbicides were also reported by Pinjari *et al.* (2016) and Sumana Ghosh *et al.* (2016).

On the basis of two years observations, it was concluded that pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha *fb* post-emergence application of bispyribac-sodium 25 g/ha found most effective and economical in controlling the weeds in wet (drum)-seeded rice in Cauvery command area of Karnataka, India.

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Indian Journal of Weed Science **53**(2): 123–128, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Indian Journal of Weed Science

Weed management efficacy of tank mix herbicides in wet-seeded rice

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Article information

DOI: 10.5958/0974-8164.2021.00023.X

Type of article: Research article

Received : 27 March 2021
Revised : 14 June 2021
Accepted : 18 June 2021

Key words
Bispyribac-sodium
Carfentrazone
Chlorimuron-ethyl
Metsulfuron-methyl
Cyperus iria
Echinochloa colona
Fenoxaprop-p-ethyl

ABSTRACT

Tank mixing of herbicides is commonly practiced by farmers for control of a wide spectrum of weeds to save labour and reduce cultivation costs. However, little is known of the probable effects of herbicide mixing on herbicide efficacy. Field experiments were conducted in 2019-20 and 2020-21 in the Kole area of Thrissur district, Kerala, India to assess the feasibility of tank mixing of commonly used herbicides. The treatments involved tank mixtures and sequential applications of fenoxaprop-p-ethyl, chlorimuron-ethyl + metsulfuron-methyl, carfentrazone, bispyribac-sodium, and cyhalofop-butyl + penoxsulam. Hand-weeded and unweeded controls were also included for comparison. Tank mixing of fenoxaprop-p-ethyl with broad-leaf herbicides reduced its efficacy against *Echinochloa colona*, as compared to sequential application. The mixture of cyhalofop-butyl + penoxsulam with chlorimuron-ethyl + metsulfuron-methyl was more effective against *E. colona* than the former applied alone. This mixture also caused greater biomass reduction of *Cyperus iria* as compared to the sole application of cyhalofop-butyl + penoxsulam. Tank mixing of fenoxaprop-p-ethyl with bispyribac-sodium was more effective against *Echinochloa stagnina* and *C. iria* as compared to their sequential application, but this mixture was less effective against *E. colona.* A similar trend was observed with total weed biomass production. Highest rice yield attributes and grain yield (3.97 t/ha) were recorded with tank mixed application of cyhalofop-butyl + penoxsulam and chlorimuron-ethyl + metsulfuron-methyl, followed by the mixture of fenoxaprop with bispyribac-sodium.

INTRODUCTION

The common practice among rice farmers is tank mixing of herbicides with the objectives of broader spectrum weed control, enhanced weed control efficiency and possibility of reducing herbicide quantity (Moss *et al.* 2007). Herbicide mixing may also result in additive or synergistic effects with potential savings in labour and labour charges. Antagonistic responses may also be elicited (Matzenbacher *et al.* 2015, Bhullar *et al.* 2016). The Kole area in Kerala state, India, is a major rice tract, covering an area of 13632 ha. This unique wetland ecosystem is situated 0.5 to 1.0 m below mean sea level and remains submerged for about six months in a year. The productivity of rice in this area is perhaps the highest in the state, mainly due to the inherent fertility of the soil (Johnkutty and Venugopal 1993). Weeds are a major limiting factor of Kole wetlands, and a total of 140 species of weeds belonging to 23 families of dicotyledons, 11 families of monocotyledons and 5 families of water fern have been identified (Sujara and Sivaperuman 2008).

Kole farmers use a variety of herbicides and their mixtures to obtain a broader spectrum of weed control at lesser cost as labour is scarce and expensive. However, the mixing is done without any knowledge of the synergistic or antagonistic effect of the herbicides in the mixtures, on weed flora. In an attempt to identify herbicide mixtures with scientific basis for weed control in the Kole lands, the tank mix application of cyhalofop-butyl with pyrazosulfuron-ethyl was found effective in managing weeds in wet seeded rice (Atheena *et al.* 2017). However, tank mixing of cyhalofop with (chlorimuron-ethyl + metsulfuron-methyl) reduced the graminicidal activity of cyhalofop. Sequential application of fenoxaprop or cyhalofop followed by chlorimuron-ethyl + metsulfuron-methyl was found to give effective control of a broad spectrum of weeds (Prameela *et al.* 2014). The present study was conducted to identify suitable combinations of different herbicides for tank mixing and application for broad spectrum weed control in wet seeded rice in the Kole area of Kerala, India.

MATERIALS AND METHODS

Field experiments were conducted during the first crop season (October to January) of the Kole lands during 2019-20 and 2020-21, in a farmer's field at Alappad in Thrissur district (geographically, the area is located between $10^0$20' and $10^0$43' North latitudes and $76^0$58' and $76^0$17' East longitudes) of Kerala. The soil of the area is clayey, belonging to the taxonomical order Inceptisol. The pH is 4.6 and the soil has 188.3 kg available N, 21.5 kg available P, and 152.4 kg available K/ha. The area has been under rice traditionally for several decades. After land preparation, plots of 5 m length and 4 m breadth were formed by bunds of 30 cm width and 15 cm height. A randomized block design with three replications was used.

Direct wet-seeding of rice variety '*Manuratna*' (100-105 days duration) was done between 12^{th} and 18^{th} October in both years. Germinated seeds were broadcasted, adopting a seed rate of 100 kg/ha. Fertilizers were applied as per the package of practices recommendation of the Kerala Agricultural University (KAU 2016). Ninety kg N, 35 kg P and 45 kg K were applied to the rice crop. One third of N, full dose of P and half dose of K were applied one week after sowing. One third of N was applied as tillering stage, and the remaining one third N and half K were applied at panicle initiation. Fields were drained 10 days before harvest of the crop, which was done between 22^{nd} and 31^{st} January in the two seasons.

Commonly used herbicides in the area were applied as tank mixed treatments, as combinations or in sequence, *i.e.* fenoxaprop-p-ethyl + chlorimuron-ethyl + metsulfuron-methyl, fenoxaprop-p-ethyl + carfentrazone, fenoxaprop-p-ethyl + bispyribac-sodium, cyhalofop-butyl + penoxsulam + chlorimuron-ethyl + metsulfuron-methyl, fenoxaprop-p-ethyl followed by (*fb*) chlorimuron-ethyl + metsulfuron-methyl, fenoxaprop-p-ethyl *fb* carfentrazone, fenoxaprop-p-ethyl *fb* bispyribac-sodium, and cyhalofop-butyl + penoxsulam *fb* chlorimuron-ethyl + metsulfuron-methyl. These were compared with a popular broad-spectrum herbicide bispyribac-sodium and a pre-mix herbicide mixture cyhalofop-butyl + penoxsulam. A hand weeded control and an unweeded control were also included as treatments. Application of herbicides was done with a knapsack sprayer filled with a flat fan nozzle.

The effect of tank mixed herbicides on species-wise weed density and biomass in rice was observed at 15 days after herbicide application. For this, a sampling quadrat of 50 × 50 cm size was placed randomly at two locations in each plot. The weed samples were dried in an oven at 70°C for 48 hours and the weed biomass was measured. Plant height and number of tillers/m^2 of rice were observed at 30 and 60 days after seeding and at harvest. At physiological maturing of the crop, number of panicles per sq. m, number of grains per panicle and percentage of filled grains were recorded on ten randomly selected plants in each plot. On maturity, the crop was harvested manually and grain and straw yields from the net pot area (12 sq. m) were recorded.

Data were subjected to analysis of variance using the statistical package 'MSTAT-C' (Freed 1986). Data on density and biomass of weeds which showed wide variation, were subjected to square root transformation, $\sqrt{x+0.5}$, to make the analysis of variance valid (Gomez and Gomez 1984) and then analyzed following ANOVA, and the means were compared based on the critical differences (least significant difference) at 0.05 level of significance. The statistical software 'WASP 2.0' was used for the analysis.

RESULTS AND DISCUSSION

Weed spectra

The study area was infested with grasses, sedges and broad-leaf weeds, but grasses and sedges dominate. The main grass species were: *Echinochloa colona*, *Echinochloa stagnina*, *Oryza sativa* f. *spontanea* (weedy rice), and *Leptochloa chinensis*. *Cyperus iria* and *Fimbristylis miliacea* were the main sedges, though several other species also occurred sporadically. *Ludwigia perennis* and *Monochoria vaginalis* were the chief broad-leaf weeds, though *Sphenoclea zeylanic*a and *Limnocharis flava* were also observed in the second season of experimentation. As the density of broad-leaf weeds was relatively very low, only their total contribution to weed biomass has been discussed.

Species-wise weed biomass

The data on weed biomass at 15 days after application would correspond to the critical period of weed control in direct-seeded rice (Rao *et al.* 2007, Chauhan and Johnson 2011). Fenoxaprop when applied in sequence with other broad-leaf herbicides was found to be more effective in controlling *Echinochloa colona* in both seasons (**Table 1**). Tank mixing with chlorimuron-ethyl + metsulfuron-methyl resulted in 51 and 47% more weed biomass, in the first and second season, respectively. Corresponding increases for tank mixing with carfentrazone and bispyribac-sodium were 34 and 35%, and 63 and

52%, respectively in 2019-20 and 2020-21. A definite decrease in effectiveness of fenoxaprop on tank mixing with broad-leaf weedkillers on *E. colona* was seen. Fenoxaprop is a very effective graminicide, used widely in the Kole area for the control of *Echinochloa* spp. and *L. chinensis*. As it controls only grasses, it is tank mixed with broad-leaf herbicides like chlorimuron-ethyl + metsulfuron-methyl and carfentrazone, and also with broad spectrum herbicides like bispyribac-sodium to get a wider swath of control. Tank mixing of these herbicides were seen to reduce the effectiveness of fenoxaprop against *E. colona*. The reduction of the efficacy of the mixture fenoxaprop with bispyribac was reported by Blouin *et al.* (2010). The antagonistic effect of the mixture of bispyribac with fenoxaprop on *Dactyloctenium aegyptium*, *Achrachne racemosa* and *L. chinensis* (Bhullar *et al*. 2016), and fenoxaprop with halosulfuron on *E. crus-galli* (Zhang *et al*. 2005) were reported earlier. The reduced efficacy of the herbicide mixture fenoxaprop and carfentrazone against *E. crus-galli*, when compared to single application of fenoxaprop, was also documented. The tank mixture of fenoxaprop and carfentrazone was however, reported to be effective in controlling *Phalaris mino*r in wheat (Singh and Singh 2005, Yadav *et al.* 2009). In the present study, fenoxaprop applied in sequence with the broad-leaf herbicides, chlorimuron-ethyl + metsulfuron-methyl and bispyribac was more effective in controlling *E. colona*, but was less effective against *L. chinensis* and broad-leaf weeds. *Echinochloa stagnina*, however, was better controlled by the tank mixture of fenoxaprop and carfentrazone than by sequential application, indicating variation in effectiveness against different species of *Echinochloa*. This mixture was also seen to be more effective against *C. iria* than sequential application of the herbicides. However, tank mixing of the pre-mix herbicide cyhalofop-butyl + penoxsulam with chlorimuron-ethyl + metsulfuron-methyl resulted in significantly lower biomass of 0.97 and 1.89 kg/ha of *E. colona* as compared to the pre-mix herbicide used alone in both seasons (2.31 and 2.24 kg/ha).

Cyperus iria was the predominant and most vigorously growing sedge in the area in both years of experimentation. Though there was not much significant difference in the effect of herbicides applied after tank mixing or in sequence on *Cyperus iria*, it was observed that tank mixing of cyhalofop-butyl + penoxsulam with chlorimuron-ethyl + metsulfuron-methyl reduced sedge biomass in

Table 1. Effect of different treatments on species-wise weed biomass (kg/ha) at 15 days after application

Treatment	*Echinochloa colona*		*Echinochloa stagnina*		*Leptochloa chinensis*		*Cyperus iria*	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Fenoxaprop-p-ethyl + chlorimuron-ethyl + metsulfuron-methyl	2.67 (6.99)	3.01 (8.74)	1.95 (4.06)	2.33 (5.43)	1.28 (1.14)	0.71 (0.00)	3.54 (12.56)	3.85 (14.92)
Fenoxaprop-p-ethyl + carfentrazone	1.75 (3.11)	2.77 (7.84)	0.71 (0.00)	1.16 (1.27)	1.28 (1.17)	1.77 (2.62)	4.01 (16.15)	4.77 (22.44)
Fenoxaprop-p-ethyl + bispyribac-sodium	1.92 (4.19)	3.09 (9.22)	1.77 (2.69)	1.28 (1.29)	1.06 (0.63)	2.30 (5.08)	3.24 (10.67)	3.06 (9.15)
Cyhalofop butyl + penoxsulam + chlorimuron-ethyl + metsulfuron-methyl	0.97 (0.58)	1.89 (3.18)	0.71 (0.00)	1.06 (0.87)	0.89 (0.37)	1.10 (1.00)	2.52 (6.39)	2.79 (9.52)
Fenoxaprop-p-ethyl *fb* chlorimuron-ethyl + metsulfuron-methyl	1.29 (1.85)	1.60 (3.65)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.50 (2.07)	3.57 (12.79)	4.04 (16.02)
Fenoxaprop-p-ethyl *fb* carfentrazone	1.15 (1.21)	1.81 (3.53)	2.08 (4.75)	1.66 (2.77)	0.71 (0.00)	0.71 (0.00)	4.97 (25.23)	4.47 (19.84)
Fenoxaprop-p-ethyl *fb* bispyribac-sodium	0.71 (0.00)	1.48 (1.99)	2.12 (4.65)	2.48 (6.16)	1.16 (1.25)	1.47 (2.83)	4.16 (17.56)	3.95 (20.41)
Cyhalofop butyl + penoxsulam *fb* chlorimuron-ethyl + metsulfuron-methyl	1.68 (2.93)	1.91 (4.03)	0.71 (0.00)	1.02 (0.73)	1.02 (0.56)	1.68 (2.88)	2.93 (8.62)	3.67 (13.62)
Bispyribac-sodium	2.98 (9.04)	3.05 (9.06)	2.67 (7.05)	2.08 (3.91)	1.42 (1.56)	2.37 (5.43)	5.52 (30.83)	5.80 (33.63)
Cyhalofop-butyl + penoxsulam	2.31 (5.01)	2.24 (4.60)	3.13 (9.97)	2.68 (6.97)	0.71 (0.00)	1.13 (1.15)	4.40 (19.42)	5.49 (30.31)
Hand weeding	1.22 (1.12)	1.98 (4.76)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.53 (2.60)	1.53 (2.39)
Unweeded control	2.84 (8.03)	4.03 (15.81)	1.49 (2.97)	2.52 (6.25)	2.54 (6.22)	2.78 (8.06)	9.89 (100.82)	9.42 (88.52)
LSD (p=0.05)	1.39	1.50	1.11	1.14	0.53	1.28	1.31	2.10

$\sqrt{x+0.5}$ transformed values, original values in parentheses comparison to application of cyhalofop-butyl + penoxsulam alone 2.52 and 2.93 kg/ha in 2019-20 and 2.79 and 3.67 kg/ha in 2020-21, respectively. A clear synergism was noticed between these two herbicides which was reflected in the total weed biomass at 15 days after application. A similar effect was observed for tank mixing of fenoxaprop with bispyribac-sodium as comparison to their sequential application 3.24 and 4.16 kg/ha in 2019-20 and 3.06 and 3.95 in 2020-21, respectively. A synergistic effect of the tank mixture of fenoxaprop and ethoxysulfuron for the control of *E. crus-galli* and *E. colona* (Bhullar *et al*. 2016), *D. aegyptium* (Chauhan 2011) and of complex weed flora (Ramachandran and Balasubramanian 2012) was documented earlier.

Echinochloa stagnina, a species as important as *E. colona* in the Kole lands did not respond as clearly as the latter to tank mixing of fenoxaprop. A significant response was seen in both years of study with regard to tank mixing of fenoxaprop with chlorimuron-ethyl + metsulfuron-methyl. In 2019-20, dry weight of *E. stagnina* was increased by 63% due to tank mixing of these two herbicides while in 2020-21, the increase was 70%. Mixing of fenoxaprop with bispyribac-sodium, was found to increase the herbicidal efficacy against *E. stagnina* as compared to their sequential application with the weed biomass reduced by 20 and 94% in the two seasons, respectively. Tank mixing with carfentrazone did not elicit a specific trend.

Leptochloa chinensis is a grass weed which had become problematic in the last two decades in the Kole area, probably due to the sole indiscriminate use of bispyribac-sodium which was reported to be ineffective in controlling the weed (Jacob *et al*. 2017). Mixing of fenoxaprop with carfentrazone was seen to reduce the efficacy of fenoxaprop against *L. chinensis* as compared to the sequential application of the herbicides. Tank mixed application resulted in 1.28 and 1.77 kg/ha of *L. chinensis* biomass in 2019-21 and 2020-21 respectively, as compared to 0.71 kg/ha for sequential application in both seasons.

Weed biomass

Grasses and sedges were the main contributors to weed biomass at 15 days after application. Mixing of fenoxaprop with chlorimuron-ethyl + metsulfuron-methyl and bispyribac-sodium increased the grass weed biomass as compared to their application in sequence in both seasons (**Table 2**). Pooled analysis of the data showed that tank mixed application of fenoxaprop with chlorimuron-ethyl + metsulfuron-methyl and bispyribac produced 60 and 8% more biomass than their application in sequence, indicating some degree of antagonism. However, tank mixing of cyhalofop-butyl + penoxsulam with chlorimuron-ethyl + metsulfuron-methyl reduced the grass biomass from 2.84 to 2.41 kg/ha. This effect was seen in the pooled data on sedges also, wherein the biomass was reduced by 20%. There was no significant difference in the response of broad-leaf weeds to tank mixing or sequential application of herbicides.

Pooled data on total weed biomass revealed that tank mixing of cyhalofop-butyl + penoxsulam and chlorimuron-ethyl + metsulfuron-methyl significantly reduced weed biomass and was at par with hand weeding. Sequential application of fenoxaprop and carfentrazone and also of fenoxaprop and bispyribac, were found to give significantly better control of weeds than their tank mixed application. Application of bispyribac-sodium or cyhalofop-butyl + penoxsulam individually was less efficacious in controlling weed growth. In spite of antagonistic effect of tank mixtures of fenoxaprop with broad-leaf herbicides against grasses, total weed biomass in the tank mixture of fenoxaprop with bispyribac was at par with the above treatment, probably due to good control of specific grasses and sedges.

Rice yield attributes and grain yield

Significantly higher number of panicles per sq.m (287), number of grains per panicle (102), percentage of filled grains per panicle (91.6) and grain yield (3.97 t/ha) were recorded with cyhalofop-butyl + penoxsulam tank mixed with chlorimuron-ethyl + metsulfuron-methyl (**Table 3**). The hand weeded control treatment was on par with this (250, 100, 89.6 and 3.95, respectively). Tank mixing of fenoxaprop with bispyribac was also at par with this treatment with regard to number of grains per panicle and percentage of filled grains per panicle.

Effective weed control by the tank mixture of cyhalofop-butyl + penoxsulam and chlorimuron-ethyl + metsulfuron-methyl was reflected in the high grain yield in this treatment, which was more than 100% greater than that in the unweeded control, while that in the tank mixture of fenoxaprop with bispyribac was 85% higher.

Tank mixing of fenoxaprop with chlorimuron-ethyl + metsulfuron-methyl, carfentrazone and bispyribac-sodium caused a decrease in the activity of fenoxaprop against grasses, probably due to

Table 2. Effect of different treatments on grass, sedge and total weed biomass (kg/ha) at 15 days after application

Treatment	Grasses			Sedges			Total		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Fenoxaprop-p-ethyl + chlorimuron-ethyl + metsulfuron-methyl	3.53 (12.90)	4.74 (22.47)	4.20 (17.69)	3.84 (14.74)	3.93 (15.49)	3.99 (16.08)	5.26 (27.90)	6.42 (41.59)	5.89 (34.74)
Fenoxaprop-p-ethyl + carfentrazone	2.77 (7.24)	3.85 (15.46)	3.33 (11.35)	4.01 (16.15)	4.71 (22.44)	4.45 (19.87)	4.83 (23.39)	6.14 (37.90)	5.53 (30.65)
Fenoxaprop-p-ethyl + bispyribac-sodium	2.95 (8.40)	4.43 (19.87)	3.73 (14.14)	3.60 (12.99)	3.11 (9.50)	3.53 (12.46)	4.61 (21.39)	5.42 (29.49)	5.04 (25.44)
Cyhalofop butyl + penoxsulam + chlorimuron-ethyl + metsulfuron-methyl	1.52 (2.13)	3.09 (9.58)	2.41 (5.85)	2.80 (7.87)	2.81 (9.63)	3.00 (9.14)	3.17 (10.07)	4.31 (19.30)	3.80 (14.68)
Fenoxaprop-p-ethyl *fb* chlorimuron-ethyl + metsulfuron-methyl	1.78 (3.64)	3.24 (12.06)	2.62 (7.85)	4.05 (16.49)	4.13 (16.69)	4.20 (17.73)	4.48 (20.13)	5.61 (31.51)	5.08 (25.82)
Fenoxaprop-p-ethyl *fb* carfentrazone	2.77 (7.50)	3.97 (16.48)	3.39 (11.99)	4.97 (25.23)	4.47 (19.84)	4.92 (24.77)	5.71 (32.92)	6.17 (38.26)	5.95 (35.59)
Fenoxaprop-p-ethyl *fb* bispyribac-sodium	2.73 (8.11)	3.89 (15.72)	3.45 (11.92)	4.31 (18.89)	4.05 (20.67)	4.43 (20.95)	5.12 (27.01)	5.89 (36.49)	5.54 (31.75)
Cyhalofop butyl + penoxsulam *fb* chlorimuron-ethyl + metsulfuron-methyl	2.53 (6.58)	3.11 (11.02)	2.84 (8.80)	3.59 (12.94)	3.70 (13.82)	3.75 (14.21)	4.40 (19.52)	5.21 (27.53)	4.83 (23.53)
Bispyribac-sodium	4.35 (20.12)	5.19 (27.54)	4.85 (23.83)	6.04 (37.14)	5.83 (34.03)	6.16 (38.45)	7.56 (57.69)	7.83 (61.57)	7.70 (59.63)
Cyhalofop-butyl + penoxsulam	4.27 (18.20)	4.71 (22.43)	4.51 (20.31)	4.49 (20.24)	5.50 (30.48)	5.07 (25.87)	6.19 (38.43)	7.95 (63.53)	7.14 (50.98)
Hand weeding	1.59 (2.20)	2.92 (9.50)	2.35 (5.73)	2.07 (4.37)	1.62 (2.69)	1.98 (3.98)	2.56 (6.74)	3.69 (14.10)	3.22 (10.42)
Unweeded control	5.63 (31.59)	9.11 (82.99)	7.56 (57.29)	9.93 (101.70)	9.48 (89.54)	10.10 (103.80)	11.55 (134.86)	13.68 (187.24)	12.68 (161.05)
LSD (p=0.05)	1.18	1.63	1.04	1.29	2.05	1.29	1.27	1.28	0.94

$\sqrt{x+0.5}$ transformed values, original values in parentheses

Table 3. Effect of different treatments on yield attributes and yield of wet-seeded rice

Treatment	Yield attributes of rice									Grain yield (t/ha)		
	No. of panicles per m^2			No. of grains per panicle			% Filled grains per panicle					
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Fenoxaprop-p-ethyl + chlorimuron-ethyl + metsulfuron-methyl	205.3	208.0	206.7	84.2	91.8	88.0	86.0	87.8	86.9	2.94	3.71	3.32
Fenoxaprop-p-ethyl + carfentrazone	192.7	188.0	190.3	83.7	77.6	80.7	83.6	79.3	81.4	2.56	3.15	2.85
Fenoxaprop-p-ethyl + bispyribac-sodium	226.7	228.0	227.3	93.3	96.0	94.7	86.8	88.5	87.7	3.28	4.03	3.65
Cyhalofop butyl + penoxsulam + chlorimuron-ethyl + metsulfuron-methyl	300.7	274.7	287.7	97.0	108.2	102.6	89.7	93.5	91.6	3.71	4.23	3.97
Fenoxaprop-p-ethyl *fb* chlorimuron-ethyl + metsulfuron-methyl	197.3	201.3	199.3	82.8	91.2	87.0	86.7	87.5	87.1	2.88	3.61	3.25
Fenoxaprop-p-ethyl *fb* carfentrazone	174.7	152.0	163.3	84.7	83.6	84.1	83.8	79.9	81.9	2.14	2.61	2.38
Fenoxaprop-p-ethyl *fb* bispyribac-sodium	195.3	196.0	195.7	87.9	78.4	83.1	83.2	81.1	82.2	2.65	3.20	2.93
Cyhalofop butyl + penoxsulam *fb* chlorimuron-ethyl + metsulfuron-methyl	208.0	226.7	217.3	90.4	93.4	91.9	86.9	88.0	87.4	3.07	3.93	3.50
Bispyribac-sodium	179.3	153.3	166.3	82.9	86.2	84.5	79.3	80.9	80.1	2.43	2.85	2.64
Cyhalofop-butyl + penoxsulam	180.7	182.7	181.7	81.6	89.6	85.6	79.1	81.9	80.5	2.50	2.91	2.70
Hand weeding	261.3	238.7	250.0	96.8	103.8	100.3	88.8	90.4	89.6	3.54	4.36	3.95
Unweeded control	157.3	102.7	130.0	75.9	81.0	78.5	77.6	78.4	78.0	1.91	2.04	1.97
LSD (p=0.05)	53.1	52.4	39.3	12.1	14.2	10.0	6.9	8.8	5.8	0.74	0.65	0.46

antagonism. Such mixtures are therefore to be avoided in areas infested chiefly with grass weeds. The tank mixture of cyhalofop-butyl + penoxsulam with chlorimuron-ethyl + metsulfuron-methyl however, registered synergism and a more effective control of grasses, sedges and broad-leaf weeds. However, the dosages of the herbicides in the mixtures have to be further investigated to arrive at conclusive results.

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Indian Journal of Weed Science **53**(2): 129–134, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of sequential application of herbicides on productivity and profitability of transplanted rice

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Article information

DOI: 10.5958/0974-8164.2021.00024.1

Type of article: Research article

Received : 3 November 2020
Revised : 13 May 2021
Accepted : 17 May 2021

Key words
Grain yield
Phytotoxicity
Post-emergence herbicide
Weed control efficiency

ABSTRACT

Field experiments were conducted during *Rabi* (winter season) 2018-19 and 2019-20 to study the effect of sequential application of herbicides on productivity and profitability of transplanted rice. Pre-emergence (PE) application of pretilachlor 750 g/ha *fb* ready-mix post-emergence (PoE) application of triafamone + ethoxysulfuron 60 g/ha recorded significantly higher grain yield which was found to be at par with two hand weedings. Sequential application of pretilachlor 750 g/ha *fb* triafamone + ethoxysulfuron 60 g/ha proved to be more effective in minimising total weed biomass (5 g/m^2), weed index (4%) and enhancing weed control efficiency (96%), grain yield (5.4 t/ha), net returns (47.0 x10^3 ₹/ha) and benefit cost ratio (1.9) than weedy check. Tank-mix application of fenoxaprop-p-ethyl 60 g/ha with ethoxysulfuron 18.75 g/ha or chlorimuron + metsulfuron 4 g/ha after pretilachlor 750 g/ha showed phytotoxicity at 5 days after application (DAA) of herbicide, which got recovered at 30 DAA.

INTRODUCTION

Rice crop suffers from various biotic and abiotic production constraints. Weed infestation has been established as one of the important factors responsible for lower productivity. Weed competition under transplanted conditions caused yield reductions up to 45% (Manhas *et al.* 2012). Generally, water management, mechanical and manual weeding and herbicides are used for weed control in rice field (Juraimi *et al.* 2013). The traditional method of weed control in Odisha is manual weeding. Usually, hand weeding is conducted two or three times during the planting season. Although it is effective, but becoming difficult due to labour scarcity, increasing cost. The effectiveness depends on the moisture content of soil at operation date. Although a number of pre-emergence herbicides provide good control of grassy weeds, but due to continuous use of such herbicides, a shift in weed flora and evolution of herbicide resistant weeds has been observed (Rajkhowa *et al.* 2006). Herbicide rotation and herbicide mixtures are two major strategies to prevent development of herbicide resistance in weeds. Herbicides with different mode of actions when mixed together, bind to different target site in weed and prevent the probability of target site resistance in susceptible species (Paswan *et al.* 2012). Technological developments on mixing herbicides with different active ingredients aiming to get a broad-spectrum control are expected to slow the emergence of weeds resistant to herbicides, reduce production costs and reduce herbicide residues (Guntoro *et al.* 2013). Therefore, the present study was undertaken with different post-emergence herbicide mixtures applied after pretilachlor (PE) to observe the effectiveness in weed control, yield improvement and economics of transplanted rice in irrigated commands.

MATERIALS AND METHODS

A field experiment was conducted during *Rabi* (winter season) 2018-19 and 2019-20 at the Regional Research and Technology Transfer Station, Chiplima (21.3^0 N latitude and 83.9^0 E longitude), Odisha University of Agriculture and Technology, Bhubaneshwar, India. The soil of experimental field was clay loam with porosity 39.28%, infiltration rate 0.26 cm/hr, water holding capacity 25.56% on weight basis, field capacity 19.7% on weight basis, permanent wilting point 10%, acidic (pH 5.65), low in organic carbon (4.7 g/kg) and available N (242 kg/ha), P (9.2 kg/ha) and medium in available K (155 kg/ha). The experiment was laid out in a randomized block design with 3 replications. The treatments comprised of ten weed management practices, *viz*. Pretilachlor750 g/ha as PE, pretilachlor 750 g/ha as PE *fb* chlorimuron ethyl + metsulfuron methyl 4g/ha as PoE, pretilachlor 750 g/ha as PE *fb* flucetosulfuron 25 g/ha as PoE, pretilachlor 750 g/ha as PE *fb* penoxsulam + cyhalofop butyl 135 g/ha as PoE, pretilachlor 750 g/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ ha as PoE, pretilachlor 750 g/ha as PE *fb* fenoxaprop-p-ethyl 60 g/ha+ ethoxysulfuron 18.75 g/ha as PoE, pretilachlor 750 g/ha as PE *fb* bispyribac-sodium 25 g/ha as PoE, pretilachlor 750 g/ha as PE *fb* triafamone + ethoxysulfuron 60 g/ha as PoE, hand weeding at 20 and 40 DAT (weed free) and weedy check.

Pre-emergence (PE) herbicides were broadcasted by mixing with 50 kg sand/ha at 3 days after transplanting and post-emergence herbicides were sprayed at 20 DAT. Post-emergence (PoE) herbicides were applied with knapsack sprayer fitted with flat fan nozzle using 375 L/ha of water. A thin film of water was maintained in the field at the time of application of pre and post-emergence herbicides. Rice variety '*MTU 1001*'was transplanted in February and harvested in May. The land was prepared by giving two ploughings each followed by planking with the help of a tractor – drawn cultivator. The puddling was done one day before transplanting. Rice crop was fertilized with N, P and K at 80, 40 and 40 kg/ha, respectively. Full dose of P and K along with half dose of N were applied as basal and remaining half dose of N was applied in two equal splits at tillering and panicle-initiation stage of the crop. Two seedlings of rice were transplanted at a spacing of 20 ×10 cm. Plant protection measures and irrigation was provided as and when required.

Data on crop phytotoxicity was assessed visually on a scale of 1-5 (Okafor 1986) at 5 and 30 DAA of herbicide. Plant chlorophyll content was measured in the flag leaf at 5 DAA and 30 DAA of herbicide using chlorophyll meter (SPAD-502, Minolta Camera Co, Osaka, Japan) as SPAD values of intact leaves (Peng *et al*. 1993). Data on weed density (number/m^2), weed biomass (g/m^2), yield attributes and yield were recorded. A quadrate of 0.5 m^2 was placed at two places in each plot to determine the density and dry weight of different weeds. Weed dry weight was recorded after drying the weed samples at 85^0C for 16 hour in hot air circulating oven (Klingman 1971). The data on weeds were subjected to square root transformation $(\sqrt{x+1})$ to normalise their distribution. weed control efficiency and weed index was calculated as per standard formula.

Economics was computed using the prevailing market prices for inputs and outputs such as rice grain (₹ 17.5 X 10^3/t), rice straw (₹ 0.8 X 10^3 /t), manual labour (₹ 0.28 X 10^3 /day), fenoxaprop-p-ethyl 9 EC (₹ 585/250 ml), flucetosulfuron 10 WG (₹ 750/100g), chlorimuron + metsulfuron 20 WP (₹ 207/8g), ethoxysulfuron15 WDG (₹ 370/50g), cyhalofop + penoxsulam 6 OD (₹ 900/l), triafamone + ethoxysulfuron 30 WG (₹ 800/45g), pretilachlor 50 EC (₹ 300/1L.), bispyribac-sodium 10 EC (₹ 835/100 ml). The net returns were computed by deducting the total cost of cultivation from the gross returns and benefit: cost ratio was calculated by dividing the net returns with the cost of cultivation. The data obtained on various parameters, *viz*. weed density, weed dry matter, yield attributes and yield were tabulated and subjected to analysis of variance techniques as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

Major weed species infesting the field were; *Echinochloa crus-galli* L., *Echinochloa colona* L., *Paspalum distichum* L., *Cyperus iria* L., *Cyperus difformis* L., *Fimbristylis miliacea* L., *Scirpus acutus* L., *Marsilea quadrifolia* L., *Ammania baccifera* L., *Alternanthera sessilis* L., *Ludwigia parviflora* L. On an average of two years, weed density of 104/m^2 was observed in weedy plots at 40 DAT which corresponds to 30.6, 33.1 and 36.6 % of grasses, sedges and broad-leaved weeds, respectively (**Table 1**).

Sedges and broad-leaved weeds were predominant at 40 DAT in all other treatments except pretilachlor 750 g/ha PE *fb* bispyribac 25 g/ha PoE and pretilachlor 750 g/ha PE *fb* triafamone + ethoxysulfuron 60 g/ha PoE. Pooled data of two years study showed that pre-emergence application of pretilachlor 750 g/ha *fb* post-emergence application of triafamone + ethoxysulfuron 60 g/ha resulted in the lowest weed density with 2 grasses, 1 sedge/m^2 and no broad-leaved weed (**Table 1**). The better performance of this treatment might be attributed to the effective control of grasses at initial stage by pretilachlor and control of broad-leaved weeds and sedges at later stages by triafamone + ethoxysulfuron, which was found to be statistically at par with pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha and pretilachlor 750 g/ha *fb* fenoxaprop -p-ethyl 60 g/ha + ethoxysulfuron 18.75 g/ha. Similar results were also reported by Hossain and Mondal (2014).

Among herbicide treatments the lowest weed biomass (5.0 g/m^2) was found in pretilachlor 750 g/ha *fb* post-emergence application of triafamone + ethoxysulfuron 60 g/ha, which was at par with pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha (**Table 2**). Post-emergence application of ready-mix triafamone + ethoxysulfuron recorded complete reduction in biomass of broad-leaf weeds. The high selectivity of herbicides to rice and non-selectivity to weeds was the reason of better control of weeds. Pretilachlor caused reduction in germination of emerging weed during initial period of growth, further post-emergence application of triafamone + ethoxysulfuron has controlled the late emerging sedges and broad-leaved weeds. Besides this treatment, pre-emergence application of pretilachlor 750 g/ha *fb* fenoxaprop-p-ethyl 60 g/ha + ethoxysulfuron 18.75 g/ha PoE also recorded low biomass of broad-leaved weeds (1.1 g/m^2). The lower biomass of broad-leaved weeds recorded in these treatments might be due to efficiency of ethoxysulfuron in the mixtures Kumar *et al.* (2013). The sedges were much problematic in the rice field of this zone. The dry matter of sedges was reduced in most of the treatments where combinations of herbicides were used. The lower biomasses of sedges were recorded with application of pretilachlor 750 g/ha *fb* post-emergence application of triafamone + ethoxysulfuron 60 g/ha, which was at par with pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha, pretilachlor 750 g/ha *fb* fenoxaprop-p-ethyl 60 g/ha + chlorimuron + metsulfuron 4 g/ha and pretilachlor 750 g/ha *fb* flucetosulfuron 25 g/ha. The lowest weed biomass of sedges was also found in pretilachlor *fb* flucetosulfuron (0.3g/m^2). Arya and Syriac (2018) reported that flucetosulfuron provided 24-32% reduction in sedge population over bispyribac-sodium.

Among the herbicide treatments, the highest weed control efficiency (96%) and lowest weed index (4%) was recorded with pretilachlor 750 g/ha *fb* post-emergence application of triafamone + ethoxysulfuron 60 g/ha, which was closely followed by pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha, pretilachlor 750 g/ha *fb* fenoxaprop -p-ethyl 60 g/ha + ethoxysulfuron 18.75 g/ha (**Table 2** and **3**). The better performance of post-emergence treatments with herbicide combinations indicates their superiority over sole application. The lowest weed control efficiency (56%) and highest weed index (30%) was found in pre-emergence application of pretilachlor 750 g/ha without application of any post-emergence herbicides.

Yield attributes and yield

Pre-emergence application of pretilachlor 750 g/ha *fb* post-emergence application of triafamone + ethoxysulfuron 60 g/ha recorded significantly higher number of tillers/hill (9.7) and grains/panicle (148), which was at par with pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha (9.3 and 141). Sole application of pretilachlor 750 g/ha as pre-emergence recorded lower tillers/hill (7.3) and grains/panicle

Table 1. Effect of weed control treatments on weed density at 40 DAT in transplanted rice

Treatment	Weed density (no./m^2) at 40 DAT											
	2018-19				2019-20				Pooled			
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total
Pretilachlor 750 g/ha PE	4.2 (17.0)	4.6 (20.0)	5.4 (28.0)	8.1 (65.0)	2.6 (6.0)	4.2 (17.0)	4.9 (23.0)	6.9 (46.0)	3.5 (11.3)	4.4 (18.7)	5.2 (25.7)	7.5 (55.7)
Pretilachlor 750 g/ha PE *fb* chlorimuron + metsulfuron 4 g/ha PoE	5.1 (25.0)	2.6 (6.0)	4.1 (16.0)	6.9 (47.0)	3.0 (8.0)	2.2 (4.0)	3.7 (13.0)	5.1 (25.0)	4.2 (16.3)	2.4 (5.0)	3.9 (14.6)	6.1 (35.9)
Pretilachlor 750 g/ha PE *fb* flucetosulfuron 25 g/ha PoE	4.4 (18.0)	1.2 (0.4)	4.7 (21.0)	6.4 (39.4)	2.8 (7.0)	1.4 (1.0)	4.0 (15.0)	4.9 (23.0)	3.7 (12.7)	1.3 (0.7)	4.4 (18.2)	5.7 (31.6)
Pretilachlor 750 g/ha PE *fb* penoxsulam + cyhalofop-butyl 135 g/ha PoE	2.2 (4.0)	2.8 (7.0)	3.3 (10.0)	4.7 (21.0)	2.2 (4.0)	2.2 (4.0)	3.5 (11.0)	4.5 (19.0)	2.2 (4.0)	2.5 (5.3)	3.4 (10.7)	4.6 (20.0)
Pretilachlor 750 g/ha PE *fb* fenoxaprop 60 g/ha + chlorimuron + metsulfuron 4 g/ha PoE	1.0 (0.0)	1.7 (2.0)	3.5 (11.0)	3.7 (13.0)	1.0 (0.0)	1.7 (2.0)	3.3 (10.0)	3.6 (12.0)	1.0 (0.0)	1.7 (2.0)	3.4 (10.3)	3.6 (12.3)
Pretilachlor 750 g/ha PE *fb* fenoxaprop 60 g/ha + ethoxysulfuron 18.75 g/ha PoE	1.0 (0.0)	2.6 (6.0)	1.4 (1.0)	2.8 (7.0)	1.0 (0.0)	2.4 (5.0)	2.0 (3.0)	3.0 (8.0)	1.0 (0.0)	2.5 (5.3)	1.7 (2.0)	2.9 (7.3)
Pretilachlor 750 g/ha PE *fb* bispyribac 25 g/ha PoE	2.2 (4.0)	1.7 (2.0)	1.0 (0.0)	2.6 (6.0)	2.0 (3.0)	1.7 (2.0)	1.0 (0.0)	2.4 (5.0)	2.1 (3.3)	1.7 (1.9)	1.0 (0.0)	2.5 (5.2)
Pretilachlor 750 g/ha PE *fb* triafamone + ethoxysulfuron 60 g/ha PoE	1.7 (2.0)	1.4 (1.0)	1.0 (0.0)	2.0 (3.0)	1.7 (2.0)	1.4 (1.0)	1.0 (0.0)	2.0 (3.0)	1.7 (2.0)	1.4 (1.1)	1.0 (0.0)	2.0 (3.1)
Hand weeding at 20 and 40 DAT	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check	7.2 (51.0)	6.2 (37.0)	6.3 (39.0)	11.3 (127.0)	3.7 (13.0)	5.7 (32.0)	6.2 (38.0)	9.2 (83.0)	5.7 (32.0)	5.9 (34.4)	6.3 (38.3)	10.3 (104.7)
LSD (p=0.05)	0.9	0.3	1.0	1.6	0.3	0.6	0.4	1.1	0.9	0.8	1.0	1.4

Square root $(\sqrt{x+1})$ transformed value, values in the parentheses is original values, *fb*: followed by

(116). Application of PoE herbicides increased the tiller number by 5.5 to 32.9% and grains/panicle by 2.6 to 27.6% (**Table 3**). Higher grains/panicle is the indication of higher photosynthetic efficiency of plants resulting in higher yield (Channappagoudar *et al.* 2008).

Two hand weedings recorded 93.1% increase in grain yield of rice over weedy check (2.9 t/ha). Among the herbicide treatments sequential application of pretilachlor 750 g/ha *fb* PoE application of triafamone + ethoxysulfuron 60 g/ha recorded higher grain yield (5.4 t/ha), which was at par with two hand weedings treatment and with pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha and pretilachlor 750 g/ha *fb* fenoxaprop-p-ethyl 60 g/ha + ethoxysulfuron 18.75 g/ha. This might have happened due to fact that competition between crops and weeds become less due to effective weed control in the treated plots. It could reduce competition between rice plant and weeds for nutrient, water, solar radiation and space. Thus, on optimal soil nutrient availability, nutrient uptake will be increased so that the needs for optimal growth and production levels will be elevated. Increasing of growth components and yield components will be followed by an increase in the grain production per hectare. The lowest grain yield (2.9 t/ha) was recorded in weedy check. This might be due to severe crop weed competition, as evident from higher weed density and biomass. Similar results were also reported by Prakash *et al.* (2011) and Bhat *et al.* (2013).

Correlation analysis

The linear relationships between weed biomass (w) at 40 DAT and grain yield (Y) of rice is given here as under, eq. (i)

$$Y = 5.245 - 0.068\,w \qquad (R^2 = 0.789) \text{ —— (i)}$$

The equation (i) explains that 78.9% variation in yield due to total weed biomass at 40 DAT could be explained by the regression. The further analysis indicated that with every unit increase in weed biomass, the grain yield of rice was expected to fall by 0.07 t/ha.

Crop injury

The phytotoxic effect on the crop was recorded at 5 and 30 DAA of herbicide (**Table 4**). Crop injury from pretilachlor 750 g/ha *fb* post-emergence application of fenoxaprop-p-ethyl 60 g/ha + chlorimuron + metsulfuron 4 g/ha and pretilachlor 750 g/ha *fb* fenoxaprop-p-ethyl 60 g/ha + ethoxysulfuron18.75 g/ha were characterised by a change in flag leaf colour to yellow, rating crop toxicity 2. Plants treated with herbicides exhibited slight phytotoxic effect at 5 DAA and recovered at 30 DAA. The grain yield was not much affected due to this phytotoxicity.

The lowest chlorophyll content was obtained in pretilachlor 750 g/ha *fb* fenoxaprop-p-ethyl 60 g/ha + chlorimuron + metsulfuron 4 g/ha (6.83) treated plants at 5 DAA of herbicide (**Table 4**). In pretilachlor

Table 2. Effect of weed control treatments on weed biomass and weed control efficiency at 40 DAT in transplanted rice

Treatment	Weed biomass (g/m^2) at 40 DAT														
	2018-19				2019-20				Pooled				WCE (%)		
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	2018-19	2019-20	Pooled
Pretilachlor 750 g/ha PE	5.5 (29.1)	5.4 (28.5)	3.5 (11.4)	8.4 (68.9)	3.4 (10.5)	5.0 (23.7)	3.2 (9.2)	6.7 (43.5)	4.6 (19.8)	5.2 (26.1)	3.4 (10.3)	7.6 (56.2)	59	49	54
Pretilachlor 750 g/ha PE *fb* chlorimuron + metsulfuron 4 g/ha PoE	7.0 (47.5)	3.5 (11.2)	3.1 (8.7)	8.3 (67.4)	4.1 (15.5)	2.9 (7.4)	2.8 (6.9)	5.6 (29.8)	5.7 (31.5)	3.2 (9.3)	3.0 (7.8)	7.0 (48.6)	60	65	63
Pretilachlor 750 g/ha PE *fb* flucetosulfuron 25 g/ha PoE	5.1 (25.5)	1.1 (0.2)	5.6 (29.9)	7.5 (55.5)	3.3 (9.7)	1.2 (0.4)	4.7 (20.9)	5.7 (31.1)	4.3 (17.6)	1.1 (0.3)	5.1 (25.4)	6.7 (43.3)	67	64	66
Pretilachlor 750 g/ha PE *fb* penoxsulam + cyhalofop-butyl 135 g/ha PoE	3.2 (9.1)	1.9 (2.6)	3.9 (14.5)	5.2 (26.2)	3.2 (9.1)	1.6 (1.6)	4.0 (15.3)	5.2 (26.0)	3.2 (9.1)	1.8 (2.1)	4.0 (14.9)	5.2 (26.1)	84	70	77
Pretilachlor 750 g/ha PE *fb* fenoxaprop 60 g/ha + chlorimuron + metsulfuron 4 g/ha PoE	1.0 (0.0)	2.7 (6.1)	3.2 (9.1)	4.0 (15.2)	1.0 (0.0)	2.7 (6.1)	3.1 (8.5)	4.0 (14.6)	1.0 (0.0)	2.7 (6.1)	3.1 (8.8)	4.0 (14.9)	91	83	87
Pretilachlor 750 g/ha PE *fb* fenoxaprop 60 g/ha + ethoxysulfuron 18.75 g/ha PoE	1.0 (0.0)	3.4 (10.4)	1.4 (1.1)	3.5 (11.4)	1.0 (0.0)	3.2 (9.2)	2.0 (3.2)	3.7 (12.4)	1.0 (0.0)	3.3 (9.8)	1.8 (2.1)	3.6 (11.9)	93	86	90
Pretilachlor 750 g/ha PE *fb* bispyribac 25 g/ha PoE	2.7 (6.2)	1.9 (2.5)	1.0 (0.0)	3.1 (8.7)	2.5 (5.2)	1.9 (2.7)	1.0 (0.0)	3.0 (7.9)	2.6 (5.7)	1.9 (2.6)	1.0 (0.0)	3.0 (8.3)	95	91	93
Pretilachlor 750 g/ha PE *fb* triafamone + ethoxysulfuron 60 g/ha PoE	2.1 (3.4)	1.7 (1.7)	1.0 (0.0)	2.5 (5.1)	2.1 (3.4)	1.6 (1.5)	1.0 (0.0)	2.4 (4.9)	2.1 (3.4)	1.6 (1.6)	1.0 (0.0)	2.4 (5.0)	97	94	96
Hand weeding at 20 and 40 DAT	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	100	100	100
Weedy check	10.1 (101.2)	7.3 (51.6)	4.1 (15.4)	13.0 (168.2)	5.2 (25.8)	6.8 (44.8)	4.0 (15.2)	9.3 (85.8)	8.0 (63.5)	7.0 (48.2)	4.0 (15.3)	11.3 (127.0)	0	0	0
LSD (p=0.05)	1.3	0.3	0.1	0.2	0.6	0.7	1.2	1.4	1.0	2.3	0.8	1.7	-	-	-

Square root ($\sqrt{x+1}$) transformed value, values in the parentheses are original values, *fb*: followed by

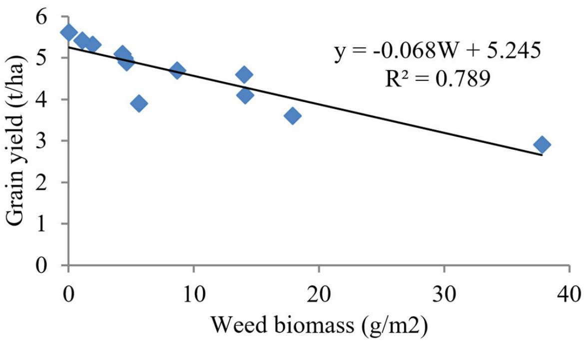

Figure 1. Weed biomass affected by weed control method on grain yield of rice

750 g/ha *fb* fenoxaprop-p-ethyl 60 g/ha + chlorimuron + metsulfuron4 g/ha treated plot, the lower chlorophyll content was due to fenoxaprop-p-ethyl as it was not affected in chlorimuron + metsulfuron (9.43) treated plots after pretilachlor. The lower chlorophyll in weedy check was probably due to crop-weed competition and lack of nutrients. Smith (1988) observed that fenoxaprop-p-ethyl in tank mixtures with bentazone applied at 4 leaf stage of grasses caused moderate (30-69%) plant chlorosis and stunting during 5 to 10 DAA. However, the crop recovered from the toxic effects after 2 to 4 weeks. In the present study slight phytotoxic effect was found in tank mixture containing fenoxaprop-p-ethyl.

Some weed control treatments manifested significant effects on plant height at harvest (**Table 4**). Significantly higher plant height was recorded in weed free treatment, which was statistically at par with pretilachlor 750 g/ha *fb* penoxsulam + cyhalofop butyl 135 g/ha (95.8 cm), pretilachlor 750 g/ha *fb* triafamone + ethoxysulfuron 60 g/ha (95.6 cm) and pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha (95.2 cm). Significantly the lowest plant height was observed with pretilachlor 750 g/ha *fb* fenoxaprop-p-ethyl 60 g/ha + chlorimuron + metsulfuron 4 g/ha (87.4 cm), which was at par with pretilachlor 750 g/ ha *fb* fenoxaprop -p-ethyl 60 g/ha + ethoxysulfuron 18.75 g/ha (85.7 cm) and weedy check plot (89 cm). In weedy check plot, plant height was affected by heavy weed infestation, while in fenoxaprop-p-ethyl + chlorimuron + metsulfuron and fenoxaprop-p-ethyl + ethoxysulfuron, had adverse effect on plant height probably due to some physiological effect. Similar results were reported by Mohapatra *et al.* **(**2018).

Economics

Sequential application of herbicides proved superior as compared to single application of herbicide of pretilachlor as pre-emergence. The highest net return (47.20× 10^3 ₹/ha) was realized from pre-emergence application of pretilachlor 750 g/ha *fb* post-emergence application of bispyribac-sodium 25 g/ha with benefit: cost ratio of 1.9. It recorded 18.2% more net return than two hand weedings plot (**Table 3**). Though weeds were controlled more effectively and grain yield was highest in hand weeding treatment net return was lower due to its higher cost of cultivation (58.6 x10^3 /ha) involving more human labour engagement and increasing labour wage. The engagement of human labours for controlling weeds was reduced with application of post-emergence herbicide, which was responsible for reduction in total cost of cultivation, resulting higher B: C ratio than weed free treatment. Only sole pretilachlor treated plot had lower B: C ratio due to less weed control efficiency as

Table 3. Effect of different weed control methods on yield attributing character and yield of rice (pooled data of two years)

Treatment	Tillers/ hill	Grains/ panicle	1000 grain weight (g)	Grain yield (t/ha)			Straw yield (t/ha)	Weed index (%)	Cost (x10^3 `/ha)	Net returns (x10^3 `/ha)	B:C ratio
				2018-19	2019-20	Pooled					
Pretilachlor 750 g/ha PE	7.3	116	23.0	4.1	3.7	3.9	4.6	30	45.46	23.37	1.4
Pretilachlor 750 g/ha PE *fb* chlorimuron + metsulfuron 4 g/ha PoE	7.7	119	22.1	4.2	4	4.1	4.9	26	44.06	28.26	1.6
Pretilachlor 750 g/ha PE *fb* flucetosulfuron 25 g/ha PoE	8.0	123	22.3	5	4.2	4.6	5.4	18	44.47	36.02	1.7
Pretilachlor 750 g/ha PE *fb* penoxsulam + cyhalofop-butyl 135 g/ha PoE	8.0	126	22.0	4.9	4.5	4.7	5.6	16	45.01	37.23	1.8
Pretilachlor 750 g/ha PE *fb* fenoxaprop 60 g/ha + chlorimuron + metsulfuron 4 g/ha PoE	8.3	129	22.4	4.7	5.1	4.9	5.8	13	45.52	40.22	1.8
Pretilachlor 750 g/ha PE *fb* fenoxaprop 60 g/ha + ethoxysulfuron 18.75 g/ha PoE	8.7	133	22.3	4.9	5.3	5.1	6.0	9	45.93	43.89	1.9
Pretilachlor 750 g/ha PE *fb* bispyribac 25 g/ha PoE	9.3	141	22.3	5.1	5.5	5.3	6.3	5	45.55	47.20	1.9
Pretilachlor 750 g/ha PE *fb* triafamone + ethoxysulfuron 60 g/ha PoE	9.7	148	23.6	5.1	5.7	5.4	6.4	4	47.45	47.04	1.9
Hand weeding at 20 and 40 DAT	10.0	150	23.8	5.3	5.9	5.6	6.6	0	58.65	39.93	1.6
Weedy check	5.3	101	22.2	2.6	3.2	2.9	3.5	47	43.55	7.78	1.1
LSD (p=0.05)	1.0	6.8	NS	0.4	0.9	0.6	0.4			29.79	0.1

Table 4. Effect of herbicide on crop toxicity rating, chlorophyll content and plant height of rice (pooled data of two years)

Treatment	Crop toxicity rating		Chlorophyll content in crop (SPAD)		Plant height at harvest (cm)
	Initial (5 DAA of herbicide)	30 DAA of herbicide	Initial (5 DAA of herbicide)	30 DAA of herbicide	
Pretilachlor750 g/ha PE	1	1	9.42	12.2	91.4
Pretilachlor750 g/ha PE *fb* chlorimuron + metsulfuron 4 g/ha PoE	1	1	9.43	12.0	91.3
Pretilachlor750 g/ha PE *fb* flucetosulfuron 25 g/ha PoE	1	1	9.42	11.5	90.6
Pretilachlor750 g/ha PE *fb* penoxsulam + cyhalofop-butyl 135 g/ha PoE	1	1	9.44	12.1	95.8
Pretilachlor750 g/ha PE *fb* fenoxaprop 60 g/ha + chlorimuron+ metsulfuron 4 g/ha PoE	2	1	6.83	10.1	85.7
Pretilachlor750 g/ha PE *fb* fenoxaprop 60 g/ha +ethoxysulfuron 18.75 g/ha PoE	2	1	7.24	10.3	87.4
Pretilachlor750 g/ha PE *fb* bispyribac 25g/ha PoE	1	1	9.47	11.1	95.2
Pretilachlor 750 g/ha PE *fb* triafamone + ethoxysulfuron 60 g/ha PoE	1	1	9.46	11.0	95.6
Hand weeding at 20 and 40 DAT	1	1	9.45	12.5	96.2
Weedy check	1	1	7.41	10.6	89.0
LSD (p=0.05)			0.8	0.4	1.2

DAA: Days after application, Crop injury is measured on a Scale 1-5, 1= No crop injury and 5 = complete crop destruction

compared to combination of pre and post-emergence herbicide treatments.

Weed control with post-emergence herbicides that contain active triafamone + ethoxysulfuron, bispyribac-sodium and fenoxaprop-p-ethyl + ethoxysulfuron after pretilachlor showed similar results with that of manual weed control. Therefore, controlling weed by the use of these herbicides was able to replace manual weeding. Although weed control with tank mix application of fenoxaprop-p-ethyl + ethoxysulfuron was similar to above herbicide, but phytotoxicity was noticed with this herbicide.

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Indian Journal of Weed Science **53**(2): 135–141, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Performance of direct-seeded rice under different nutrient and weed management practices

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Article information

DOI: 10.5958/0974-8164.2021.00025.3

Type of article: Research article

Received : 2 May 2021
Revised : 18 June 2021
Accepted : 22 June 2021

Key words

Agronomic management index
Weed control efficiency
Weed indices
Weed management index
Weed persistence index

ABSTRACT

Manipulation of crop fertilization with weed management is a promising agronomic practice in reducing weed interference in crops. With this hypothesis, an experiment was conducted at the Birsa Agricultural University, Ranchi, Jharkhand, India during rainy seasons (*Kharif*) of 2018 and 2019 to study the effect of nutrient and weed management practices on dry direct-seeded rice under split plot design. 100:50:40 kg/ha of N:P:K along with pretilachlor 750 g/ha (pre-emergence) *fb* bispyribac-Na 25 g/ha (post-emergence) recorded highest grain yield (5.54 t/ha)owing to higher effective tillers and grains/panicle to the extent of 73.5 and 82.8 percent, respectively compared to the minimum attained under lowest nutrient level 60:30:20 kg/ha of N:P:K under weedy check. The combination of 100:50:40 kg/ha of N:P:K along with pretilachlor750 g/ha *fb* bispyribac-Na 25 g/ha recorded maximum weed management index (5.11) and agronomic management index (4.11) at 60 DAS and higher gross returns (₹ 1,16928/ha), net returns (₹ 93376/ha) and B:C (3.13) as compared to rest of the treatment combinations.

INTRODUCTION

Dry direct-seeded rice (DDSR) is an alternative to puddled transplanted rice (PTR) in South-East Asia (Pandey and Velasco 2002). In conventionally grown rice, 20-30 days old rice seedlings are transplanted in puddled fields. It requires huge number of labourers as well as large quantity of water . Out of total water requirement of approximately 1500 mm, 200-250 mm is used only for puddling (Guerra *et al.* 1998). DDSR technique is becoming popular nowadays due to its low-input demanding nature. Jharkhand has 1.5 million ha under rice cultivation with production of 4.3 million ton and average productivity of 2.8 t/ha (Anonyms 2020). Dry direct-seeding of rice is a common practice among farmers in West Singhbhum and Saraikela -Kharsawan Districts of Jharkhand due to uncertainty of monsoon, water crisis as well as scarcity of labour (Barla and Upasani 2018). Tansplanting of rice is badly affected by the vagaries of monsoon. Realizing the constraints of transplanted rice the area under DDSR is increasing and it may be around 20% of total area under rice in Jharkhand. The DDSR culture is subject to greater weed competition than transplanted rice because both weed and crop seeds emerge at the same time and compete with each other right from its germination time resulting huge loss in grain yield (Rao *et al.* 2007). A weed free period for the first 30-45 DAS (days after sowing) is required to avoid any loss in yield. Herbicides offer the foremost effective, economical and practical way of weed management. Pre-emergence herbicides in combination with post-emergence herbicides are needed to control weeds in DSR because of diverse and intensified weed flora.

In addition to weed management problems in DSR, the nutrient management is also very tricky. Various researches under DSR have been conducted on weed management and nutrient management in isolation. The combined effect of weed and nutrient management may have different impacts than their individual effects considering better plant growth under effective weed management thus the nutritional requirement of crop may change. Hence, need for balancing nutrient requirement with appropriate weed management was considered as an objective of the present investigation.

MATERIALS AND METHODS

The experiment was conducted at Birsa Agricultural University, Ranchi, Jharkhand, India situated at 23°17´ North latitude and longitude of 85°19´ East with an altitude of 625 m above the mean sea level. The selected site represents the major medium land rice growing area of the region. The experimental soil was acidic in nature with pH 5.2, organic carbon 3.87 g/kg, low in available nitrogen (175.61 kg/ha), medium in available phosphorus (22.17 kg/ha) and potassium (128 kg/ha). The experiment was laid out in a split plot design with 3 nutrient management practices (F1-60:30:20, F2-80:40 30 and F3-100:50:40 N:P:K kg/ha) in main plots and 5 weed management practices (pretilachlor 50 EC 750 g/ha pre-emergence (PE), bispyribac-Na 10 EC 25 g/ha post-emergence (PoE) at 20 DAS, pretilachlor 50 EC 750 g/ha PE *fb* bispyribac-Na 10 EC 25 g/ha PoE at 20 DAS, hand weeding (20 and 40 DAS) and unweeded check) in sub-plots replicated three times. Seeds of rice variety *'Sahbhagi Dhan'* (medium duration variety of 120-125 days) were sown. Direct line sowing was performed manually on 22[nd] and 25[th] June 2018 and 2019, respectively at a seeding depth of 2 to 3 cm after basal application of fertilizer in rows spaced at 20 cm using 70 kg seed/ ha. The crop was harvested on 25[th] and 28[th] October 2018 and 2019, respectively. Nutrients as per treatment were applied through urea, diammonium phosphate and muriate of potash, respectively. Full dose of phosphorus and potassium as basal and half dose of nitrogen were applied in all the treatments. Remaining half nitrogen was applied in two equal splits at maximum tillering and panicle initiation stages by top dressing. The herbicides were applied as per treatment by manually operated back pack sprayer using a flat-fan nozzle at a spray volume of 500 L/ha so as to spray the fluid uniformly throughout the targeted area. Hand weeding was enacted as per treatment by pulling out weeds manually. In case of hand weeding plot the weeds were uprooted at 20 and 40 DAS. The weed density of different weed species in each plot were recorded at 30 and 60 DAS. Different weed indices were calculated by using following formula as suggested by Mishra and Misra (1997).

Weed management Index (WMI) = {(YT"YC) ÷ YC} ÷ {(WC" WT) ÷ WC}

Where, YT = Yield of treated plot, YC= Yield of control (weedy check) plot, WC = Weed dry weight in control (weedy check) plot, WT= Weed dry weight in treated plot.

Agronomic management Index (AMI) = {(YT-YC)/YC} – {(WC-WT/WC)}/ (WC-WT)/WC)

Where, YT = Yield of treated plot, YC= Yield of control (weedy check) plot, WC = Weed dry weight in control (weedy check) plot, WT= Weed dry weight in treated plot.

Nutrient uptake (N, P and K) of crop were calculated in kg/ha from corresponding nutrient content in grain and straw yield by using given formula;

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content (\%) x yield (kg/ha)}}{100}$$

Correlation matrix between grain yield of rice (kg/ha) and various growth, yield attributes, grain yield, N, P,K uptake, weed density and weed dry weight were established by adopting the least square technique.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with *Fimbristylis miliacea* (L.) (29.59%), *Aeschynomene indica* (L.) (17.05%), *Echinochloa crus-galli* (L.) P Beauv. (14.79%), *Cyperus iria* (L.) (11.06%), *Eleusine indica* Gaerts. (9.27%), *Commelina benghalensis* (L.) (7.47%), *Ageratum conyzoides* (L.) (4.78%), *Cynotis axillaris* (L.) D.Don (2.85%), *Cynodon dactylon* (L.) (1.65%) and *Dactyloctenium aegyptium* (L.) (1.49%). Surin *et al.* (2019) also reported three categories of weed species throughout the crop growth in direct-seeded rice and reported *Dactyloctenium aegyptium, Cyperus iria, Elusine indica and Fimbristylis miliacea* were predominant.

Application of higher nutrient level 100:60:40 kg/ha of N:P:K significantly reduced weed density to the extent of 47.91 and 22.60% at 30 and 60 DAS, respectively compared to the lowest level of nutrient level *i.e.* 60:30:20 kg/ha of N:P:K (**Table 1**). This may be due to selective advantages to crop plant in the form of better growth and development. Among weed management practices, application of pretilachlor 750 g/ha *fb* bispyribac-Na at 25 g/ha being similar to hand weeding twice at 20 and 40 DAS recorded significantly reduced weed density to the tune of 83.6% at 30 DAS and 81.7% at 60 DAS compared to unweeded check. It is in conformity with the finding of Chauhan *et al.* (2013). Pretilachlor being chloroacetanilide class of herbicides, inhibits growth and very long chain fatty acids and also reduces cell division. While, bispyribac-sodium inhibits the enzyme acetolactate synthase (ALS) and the subsequent biosynthesis of essential amino acids, which in turn interferes with cell division and causes cessation of plant growth, leading to chlorosis, necrosis and death of sensitive plants. In insensitive plants, such as rice, bispyribac-sodium is rapidly metabolized to non herbicidal products.

The interaction effect of nutrient and weed management (**Table 2**) revealed that application of 100:50:40 kg/ha of N:P:K along with pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha recorded significantly reduced weed density at 30 DAS to the tune of 92.8% compared to 60:30:20 kg/ha of N:P:K under unweeded check. While at 60 DAS, application of 80:40:30 kg/ha of N:P:K with hand weeding twice recorded 81.3% reduced weed density at 30 DAS compared to 60:30:20 kg/ha of N:P:K under unweeded check.

Nutrient levels had remarkable effect on weed dry matter accumulation in rice crop. Application of 100:50:40 kg/ha of N:P:K controlled weeds effectively as it significantly reduced weed dry weight to the extent of 48.4 and 29.7 percent at 30 and 60 DAS compared with lowest level of nutrient *i.e.* 60:40:20 kg/ha of N:P:K which recorded 602.44 and 423.84 g/m^2 weed dry weight.

The interaction of nutrient and weed management (**Table 2**) revealed that application of 100:50:40 kg/ha of N:P:K along with pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha recorded significantly reduced weed dry matter at 30 DAS to the tune of 88.2% compared to 60:30:20 kg/ha of N:P:K under unweeded check. While at 60 DAS, application of 80:40:30 kg/ha of N:P:K with hand weeding twice recorded 92.3% reduced weed dry matter compared to 60:30:20 kg/ha of N:P:K under unweeded check .

Effect on crop

Application of nutrient level 100:50:40 kg/ha of N:P:K recorded significantly higher plant height to the extent of 25.9 and 14.1% compared to 80:40:30 and 60:30:20 kg/ha of N:P:K (**Table 3**).

Yield attributes

Application of nutrient levels 100:50:40 kg/ha of N:P:K recorded significantly higher values of effective tillers (292/m^2), number of grains/panicle (111), panicle length (20.47cm) and 1000 grain weight (23.61 g) (**Table 3**). The increase was to the extent of 21.2, 42.3, 24.4 and 9.3%, respectively, compared to minimum recorded under 60:30:20 kg/ha of N:P:K. Similar findings were also reported by Patel *et al.* (2018) who reported that significantly higher plant height and number of tillers /meter row

Table 1. Weed density and weed dry matter as influenced by nutrient and weed management (pooled data of two years)

Treatment	30 DAS Weed density(no./m^2)		60 DAS Weed dry matter (g/m^2)	
	30 DAS	60 DAS	30 DAS	60 DAS
Nutrient level (N: P: K kg/ha)				
60:30:20	29.4(956)	14.4(236)	23.8(602)	19.4 (423)
80:40:30	24.0(645)	14.3(221)	19.9(432)	17.7(340)
100:50:40	21.1(498)	13.0(182)	17.0 (311)	16.4(298)
LSD (p=0.05)	0.92	0.11	1.21	2.39
Weed management (W)				
Pretilachlor 750 g/ha	22.4(506)	12.1(149)	19.6 (393)	18.6 (347)
Bispyribac-Na 25 g/ha	33.7(1164)	17.2(297)	25.0(639)	19.3 (377)
Pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha	13.9(205)	11.0(121)	12.9(173)	14.9 (223)
Hand weeding (20 & 40 DAS)	19.2 (379)	8.7(77)	15.9(261)	9.8(97)
Weedy check	35.0(1245)	20.4(421)	27.7 (777)	26.6(725)
LSD (p=0.05)	0.95	0.07	1.31	1.62
Interaction (F x W)				
LSD (p=0.05)	1.61	0.13	2.24	2.77

*Data in parentheses (original value) was subjected to $\sqrt{x+0.5}$ transformation

Table 2. Weed density and weed dry matter as influenced by interaction of nutrient and weed management (pooled data of two years)

Treatment	Weed density (no./m^2) 30 DAS			Weed density 60 DAS			Weed dry matter (g/m^2) 30 DAS			Weed dry matter 60 DAS		
	F_1	F_2	F_3	F_1	F_2	F_3	F_1	F_2	F_3	F_1	F_2	F_3
Pretilachlor 750 g/ha	23.9 (569)	23.6 (556)	19.8 (392)	12.7 (160)	13.7 (186)	9.7 (94)	23.5 (551)	18.8 (355)	16.4 (272)	17.0 (288)	20.5 (420)	18.2 (332)
Bispyribac-Na 25 g/ha	40.6 (1651)	33.2 (1101)	27.2 (739)	15.9 (252)	16.9 (286)	20.4 (414)	28.7 (822)	26.0 (674)	20.5 (419)	22.6 (512)	18.1 (328)	17.0 (290)
Pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha	18.1 (327)	12.9 (167)	10.9 (120)	11.6 (134)	11.8 (138)	10.9 (118)	15.9 (254)	12.2 (151)	10.6 (113)	16.7 (278)	13.9 (192)	14.0 (196)
Hand weeding (20 and 40 DAS)	23.6 (558)	17.2 (297)	16.8 (281)	9.8 (96)	8.6 (74)	9.1 (82)	19.3 (373)	15.0 (227)	13.5 (182)	10.4 (107)	10.6 (112)	8.5 (72)
Weedy check	40.9 (1675)	33.2 (1103)	31.0 (958)	19.9 (396)	20.5 (421)	19.3 (371)	31.8 (1010)	27.4 (753)	23.8 (566)	30.2 (931)	25.4 (645)	24.3 (596)
LSD (p=0.05)		1.62			0.13			2.24			2.77	

*Data in parentheses (original value) was subjected to $\sqrt{x+0.5}$ transformation; F_1: 60:30:20 N:P:K; F_2: 80:40:30 N:P:K; F_3: 100:50:40 N:P:K length were recorded with application of pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS in DSR. This may be owing to better growth of rice plant under reduced crop weed competition aroused due to adequate nutrient supply accompanied by effective weed management.

Application of 100:50:40 kg/ha of N:P:K recorded 44.1 and 103.6% significantly higher grain yield compared to 80:40:30 kg/ha of N:P:K and 60:30:20 kg N:P:K/ha. Similarly 100:50:40 kg/ha of N:P:K also recorded significantly higher straw yield compared to lower levels of NPK. Among weed management practices, application of pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha being similar to hand weeding at 20 and 40 DAS recorded significantly higher yield attributes like effective tillers (305/m^2), number of grains/panicle (102), panicle length (20.88 cm) and 1000 grain weight (23.69 g) which resulted in significantly higher grain yield (4095 kg/ha) and straw yield (5422 kg/ha). Mewada *et al.* (2016) reported that amongst different weed management treatments, maximum grain and straw yield were recorded in treatment where hand weeding was done twice 20 and 40 DAS, maintained its superiority over rest of the treatments and it was followed by those treatments where pre-emergence application of herbicide was followed by post-emergence herbicide.

The interaction of nutrient and weed management practices revealed that application of 100:50:40 kg/ha of N:P:K combined with application of pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha recorded significantly higher grain yield (5542 kg/ha) however, it was similar to 100:50:40 kg/ha of N:P:K along with hand weeding (**Table 4**). The reason can be assigned to yield attributes like effective tillers and number of grains which were higher under this treatment combination.

Table 4. Grain yield of rice as influenced by interaction of nutrient and weed management practices (pooled data of two years)

Treatment	Grain yield (t/ha) nutrient levels		
	F_1	F_2	F_3
Pretilachlor 750 g/ha	1.46	1.91	3.78
Bispyribac-Na 25 g/ha	1.26	1.68	2.23
Pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha	2.64	4.10	5.54
Hand weeding (20 and 40 DAS)	2.52	3.56	5.08
Weedy check	0.84	1.06	1.12
LSD (p=0.05)		0.74	

F_1: 60:30:20 N:P:K; F_2: 80:40:30 N:P:K; F_3: 100:50:40 N:P:K

Economics

Combination of 100:50:40 kg/ha of N:P:K and pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha recorded significantly higher gross returns (₹ 1,16,928/ha), net returns (₹ 93,376/ha) and B:C (3.13) as compared to rest of the treatment combinations.

Dry matter partitioning in rice plant

The trend of dry matter partitioning in different plant parts showed that leaf continued to accumulate dry matter up to 60 DAS and thereafter it reduced. The percentage range of dry matter by leaves accumulation were 40.4, 24.8, and 12.6% of total dry matter at 60 DAS, 90 DAS and at crop maturity. While in case of culm, the dry matter accumulation became prominent from 60 DAS and remained almost similar up to 90 DAS and thereafter it started reducing. The mean percent range of dry matter accumulation by culm was 59.7, 38.1 and 32.2% of

Table 3. Plant height, yield attributes, yield and economics of rice as influenced by nutrient and weed management practices (pooled data of two years)

Treatment	Plant height (cm)	Effective tillers (no./m^2)	No. of grains/ panicle	Panicle length (cm)	1000 grain weight (g)	Yield (t/ha) Grain			Straw			Gross returns (₹/ha)	Net returns (₹/ha)	B:C
						2018	2019	Pooled	2018	2019	Pooled			
Nutrient level (N: P: K kg/ha)														
60:30:20	83.3	241	78	16.45	21.60	1.81	1.67	1.74	2.26	2.59	2.42	37428	15626	-0.24
80:40:30	91.9	277	101	19.79	22.61	2.61	2.32	2.46	3.93	3.60	3.76	53552	30540	0.42
100:50:40	104.9	292	111	20.47	23.61	3.44	3.66	3.55	5.84	5.61	5.73	77806	53579	1.32
LSD (p=0.05)	8.7	25	11	1.08	0.90	0.24	0.67	0.29	1.32	0.88	0.41	4298	4298	0.18
Weed management (W)														
Pretilachlor 750 g/ha	96.0	250	95	18.46	22.66	2.48	2.29	2.38	3.97	4.18	4.07	52682	31225	0.49
Bispyribac-Na 25 g/ha	90.7	268	99	18.66	22.74	1.76	1.69	1.73	2.59	2.72	2.65	37575	16348	-0.18
Pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha	101.2	305	102	20.88	23.69	3.83	4.35	4.09	5.00	5.85	5.42	87335	65096	1.98
Hand weeding (20 & 40 DAS)	97.4	311	105	19.81	23.90	3.92	3.52	3.72	4.62	5.37	4.99	79467	49766	0.99
Weedy check	81.3	217	84	16.71	20.05	1.10	0.92	1.01	3.86	1.56	2.71	24252	3807	-0.79
LSD (p=0.05)	4.6	19	10	1.47	0.73	0.32	0.86	0.43	1.24	1.26	0.74	8000	8000	0.31
Interaction (F x W)														
LSD (p=0.05)	8.0	33	18	2.52	1.25	0.56	1.47	0.74	NS	2.17	1.27	13700	13700	0.54

total dry matter at 60 and 90 DAS and at crop maturity. Similarly, the dry matter accumulation by panicle of rice continued to increase up to maturity of crop and the mean per cent dry matter accumulation were in the range of 37.1 and 55.1% of total dry matter at 90 DAS and at maturity. Data on dry matter production of rice plants (**Table 5**) revealed that it continued to increase slowly till maturity of crop.

Weed indices

Data on influence of nutrient and weed management practices on different weed indices revealed that weed control efficiency was not affected by nutrient levels. However, weed management index and agronomic management index were recorded significantly higher by application of higher nutrient levels *i.e.* 100:50:40 kg/ha of N:P:K at 60 DAS to the tune of 17.9, and 314.6% compared to minimum recorded under 60:40:20 kg/ha of N:P:K.

Among weed management practices, application of pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha at 30 DAS and hand weeding twice (20 and 40 DAS) at 60 DAS, recorded maximum weed control efficiency *i.e.* 78.1 and 85.5%, respectively, while pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha also recorded maximum weed management index (3.15) at 60 DAS.

Nutrient uptake

Nutrient level of 100:50:40 kg/ha of N:P:K recorded maximum nitrogen, phosphorus and potassium uptake by total rice biomass *i.e.* 60.22, 12.98 and 75.21 kg/ha which was 116.9, 104.7 and 71.5% higher compared to minimum recorded under 60:30:20 kg/ha of N:P:K, respectively (**Table 7**). Improvement in nitrogen uptake with increased nitrogen levels was also reported by Sandhu and Mahal (2014).

Table 5. Dry matter accumulation by different plant parts of rice as influenced by nutrient and weed management practices (pooled data of two years)

Treatment	Dry matter accumulation by rice plant (g/m^2)											
	30 DAS	60 DAS			90 DAS				Maturity			
	Leaf	Leaf	Stem	Total	Leaf	Stem	Panicle	Total	Leaf	Stem	Panicle	Total
Nutrient level (N:P:K kg/ha)												
60:30:20	126.87	169.58	248.95	418.53	158.48	242.60	236.39	637.46	81.37	204.61	356.29	642.27
80:40:30	131.30	173.79	260.05	433.83	162.88	258.35	251.72	672.95	87.55	225.07	377.56	690.18
100:50:40	137.57	183.40	273.34	456.73	178.69	267.71	260.67	707.07	91.82	232.93	401.95	726.71
LSD (p=0.05)	1.54	12.28	18.18	18.30	14.21	18.65	19.16	45.31	4.55	16.38	32.65	39.56
Weed management (W)												
Pretilachlor 750 g/ha	130.11	174.58	249.52	424.10	158.88	255.24	248.62	662.73	87.23	226.95	392.26	706.44
Bispyribac-Na 25 g/ha	126.89	170.80	235.66	406.46	157.14	243.99	237.69	638.83	83.04	210.77	353.67	647.47
Pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha	142.17	185.89	308.54	494.44	187.59	287.51	280.09	755.20	95.78	239.82	428.41	764.00
Hand weeding (20 and 40 DAS)	137.11	184.56	300.61	485.17	184.80	276.21	269.01	730.01	98.66	240.44	422.23	761.34
Weedy check	123.28	162.09	209.56	371.65	144.99	218.14	212.56	575.69	69.85	186.37	296.44	552.66
LSD (p=0.05)	5.06	5.27	32.29	32.57	9.62	16.89	16.91	36.77	7.82	37.79	33.25	56.69
Interaction (F x W)												
LSD (p=0.05)	8.67	9.03	55.29	55.78	16.47	28.93	28.95	62.97	13.39	64.72	56.94	97.08

Table 6. Weed management index and Agronomic management index as influenced by nutrient and weed management practices (pooled of two years)

Treatment	Weed management index		Agronomic management index	
	30 DAS	60 DAS	30 DAS	60 DAS
Nutrient level (N: P: K kg/ha)				
60:30:20	1.93	1.28	1.13	0.48
80:40:30	2.65	1.36	1.85	0.56
100:50:40	3.99	2.79	3.19	1.99
LSD (p=0.05)	NS	0.67	NS	0.67
Weed management (W)				
Pretilachlor 750 g/ha	2.72	2.35	1.72	1.35
Bispyribac-Na 25 g/ha	4.93	1.12	3.93	0.12
Pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha	3.04	3.15	2.04	2.15
Hand weeding (20 & 40 DAS)	3.58	2.43	2.58	1.43
Weedy check	0.00	0.00	0.00	0.00
LSD (p=0.05)	1.47	0.40	1.47	0.40
Interaction (F x W)				
LSD (p=0.05)	2.51	0.69	2.51	0.69

Nitrogen, phosphorus and potassium uptake by rice biomass was significantly influenced by different weed management practices. Pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha being similar to hand weeding at 20 and 40 DAS, recorded 65.7, 14.6 and 86.2 kg nitrogen, phosphorus and potassium uptake by rice biomass. The increase was 344.2, 422.0 and 400.4% over weedy check. Higher nutrient uptake under these treatments was due to better control of weeds leading to lower depletion of nutrients by weeds and higher nutrient uptake by rice crop. Weedy check resulted in significantly lower nutrient uptake. Many researchers have also reported that weeds are capable of absorbing nutrients faster and in relatively bigger amounts than crop plants (Gudi and Somasundaram, 2017 and Blackshaw *et al.* 2005).

The combination of nutrient level 100:50:40 kg/ha of N:P:K along with pretilachlor 750g/ha *fb* bispyribac-sodium 25g/ha was similar to 100:50:40 kg/ha of N:P:K along with hand weeding at 20 and 40 DAS in respect of nitrogen (94.51 kg/ha), phosphorus (19.80 kg/ha) and potassium (124.10 kg/ha) uptake by rice biomass.

Microbial study of soil

Data on microbial population after harvest of rice crop revealed that application of nutrients as well as weed management practices increased actinomycetes, bacterial and fungal population in soil over original status (**Table 8**). Application of 100:50:40 kg/ha of N:P:K recorded maximum actinomycetes and bacterial population in soil while at higher level of nutrient the fungal population reduced. Basak *et al.* (2012) advocated for balanced supply of nutrients, which in turn might maintain the higher population of microbes. These findings were in the line with the results reported by Selv i*et al.* (2004). Ingle *et al.* (2014) also reported that imbalanced nutrition caused decline in microbial population as compared to balanced fertilization. Among weed management practices all treatments were similar in terms of actinomycetes population while application of pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha recorded maximum bacterial and fungal population however, in case of actinomycetes population, it was similar to rest of the treatments. Interaction of nutrient level and weed management practices was found to significantly affecting fungal population**.**

The combination of nutrient level 60:30:20 kg/ha of N:P:K along with pretilachlor 750 g/ha *fb* bispyribac-sodium 25 g/ha, being similar to 60:30:20 kg/ha of N:P:K along with hand weeding at 20 and 40 DAS, and 80:40:30 kg/ha of N:P:K along with pretilachlor 750 g/ha *fb* bispyribac-sodium 25g/ha, recorded maximum fungal count *i.e.*, 47.76 x10^4 CFU /g of soil, which was 108.01 percent higher than nutrient level 100:50:40 kg kg/ha of N:P:K along with pretilachlor 750g/ha *i.e.*,22.96 x10^4 CFU /g of soil.

Correlation studies

The dependence of the grain yield was found to be significantly and positively correlated with dry matter accumulation by different plant parts *viz.* leaf 30 DAS (r=0.98), 60 DAS (r=0.97), 90 DAS (r=0.95) and at maturity (r=0.87); culm 60 DAS (r=0.90), culm 90 DAS (r=0.94), at maturity (r=0.86); panicle at 90 DAS (r=0.94) and at maturity (r=0.88); and total dry matter accumulation by rice plant at 30 DAS (r=0.98), at 60 DAS (r=0.93), at 90 DAS (r=0.95), and at maturity (r=0.89) observed in the present experiment.

Table 7. Nutrient uptake in direct-seeded rice at harvest as influenced by nutrient level and weed management practices

Treatment	Nutrient uptake (kg/ha)								
	Nitrogen			Phosphorus			Potassium		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Nutrient level (N: P: K kg/ha)									
60:30:20	17.91	9.84	27.76	3.89	2.45	6.34	3.19	39.40	42.59
80:40:30	27.46	14.44	41.90	5.77	3.91	9.68	5.32	50.92	56.23
100:50:40	39.50	20.72	60.22	8.25	4.72	12.98	8.25	66.95	75.21
LSD (p=0.05)	2.48	1.09	3.20	0.61	0.44	0.92	0.96	6.81	7.25
Weed management (W)									
Pretilachlor 750 g/ha	25.74	13.25	38.99	5.19	3.49	8.69	4.93	48.41	53.34
Bispyribac-Na 25 g/ha	17.91	9.43	27.35	3.98	2.46	6.44	3.25	34.00	37.25
Pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha	42.86	22.86	65.72	9.23	5.31	14.54	8.33	77.91	86.23
Hand weeding (20 and 40 DAS)	44.65	24.24	68.89	9.73	5.93	15.66	9.72	84.66	94.37
Weedy check	10.29	5.23	15.51	1.72	1.28	3.00	1.73	17.13	18.86
LSD (p=0.05)	4.14	2.60	6.29	0.77	0.49	1.09	0.88	9.09	9.63
Interaction (F x W)									
LSD (p=0.05)	7.08	4.45	10.77	1.32	0.84	1.86	1.51	15.57	16.49

Table 8. Soil microbial population as influenced by nutrient level and weed management practices in direct-seeded rice

Treatment	Microbial population		
	Actinomycetes (Cells /g of soil) x 10^6	Bacteria (Cells/g of soil) x 10^5	Fungi (CFU /g of soil) x 10^4
Nutrient level (F) (N: P: K kg/ha)			
60:30:20	35.02	103.57	42.81
80:40:30	38.10	105.65	42.17
100:50:40	48.05	109.63	36.43
LSD (p=0.05)	1.73	3.53	1.91
Weed management (W)			
Pretilachlor 750 g/ha	38.49	106.30	35.64
Bispyribac-Na 25 g/ha	39.20	101.73	39.37
Pretilachlor 750 g/ha *fb* bispyribac-Na 25 g/ha	38.71	110.28	43.07
Hand weeding (20 & 40 DAS)	39.84	108.13	41.54
Weedy check	45.70	104.98	42.73
LSD (p=0.05)	2.22	4.43	1.98
Interaction (F x W)	30.20	95.40	33.60
LSD (p=0.05)			
Nutrient level (F)(N: P: K kg/ha)	3.80	7.59	3.39

The weed dry matter and weed density/m^2 were negatively correlated at 1% level of significance with rice grain yield at 30 DAS (r= 0.86 and 0.73), and 60 DAS (r= 0.80 and 0.72). Plant height was positively correlated (r=0.88) with yield attributes, *viz.* effective tillers/m^2 (r=0.87), number of grains/panicle (r=0.77), panicle length (r=0.75) with rice grain yield at 1% level of significance. Similarly, the correlation between N, P, K uptake and grain yield of rice revealed that N uptake (r =0.98), P uptake (r = 0.98) and K uptake (r = 0.94) showed significant positive correlation with grain yield of rice at 1% level of significance.

It may be concluded that application of 100:50:40 kg N:P:K per hectare along application of pretilachlor 750g/ha PE *fb* bispyribac sodium 25g/ha post-emergence was found more effective and economical in direct-seeded rice.

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Indian Journal of Weed Science 53(2): 142–145, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Management of field sowthistle (*Sonchus oleraceus* L.): an emerging threat in winter crops

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Article information

DOI: 10.5958/0974-8164.2021.00026.5

Type of article: Research article

Received : 4 December 2020
Revised : 29 March 2021
Accepted : 3 April 2021

Key words
Biology
Chickpea
Emergence
Impact and management
Sonchus arvesnsis
Wheat

ABSTRACT

In central India, most of the arable and disturbed non-arable lands are vulnerable to invasions of field sowthistle (*Sonchus oleraceus* L.) during winter and summer. Its infestation has threatened the resident biodiversity and has also posed the possibility of spread to adjoining areas. The present study was conducted to know the biology of *S. oleraceus,* its impact and suggest suitable management strategies to restrict its further spread. In wheat, pendimethalin *fb* metsulfuron-methyl (678 *fb* 4 g/ha) recorded the lowest density and biomass of *S. oleraceus* (2 no./m^2 and 0.5 g/m^2, respectively) with 92.3% weed control efficiency (WCE) followed by clodinafop + metsulfuron (60+4 g/ha), which were statistically comparable. Similarly, in chickpea, pendimethalin + imazethapyr (900+60 g/ha) recorded the lowest density and biomass of *S. oleraceus* (3 no./m^2 and 1.1 g/m^2, respectively) with 86.9% WCE, where density was comparable to propaquizafop + imazethapyr (50+75 g/ha). The lower density of *S. arvesnsis* recorded with higher grain yield of wheat (5.10 t/ha) and seed yield of chickpea (2.25 t/ha). The highest density and least yield recorded in control plots.

INTRODUCTION

Crop productivity is severely influenced by biotic and abiotic stresses. Among biotic factors, weeds are major yield reducers and may cause yield penalty up to 33-37% (Choudhary and Dixit 2018). In recent past, it has experienced that most of the arable and non-arable lands are vulnerable to invasions of field sowthistle (*Sonchus oleraceus* L.) (Andreasen and Stryhn 2008, Suryawanshi *et al.* 2018) and threatened the resident biodiversity. *S. oleraceus* is a plant of Asteraceae family, and originated from Europe and Western Asia. This is a dicotyledonous winter annual plant and considered an invasive species in several parts of the world. In India, it is being present in North-Eastern states, Himachal Pradesh, Jammu and Kashmir, Uttarakhand and West Bengal and also considered invasive (Chandra 2012). Leaves are thin, soft, dark green with a purple vein with dimension of 10-22 × 3-10 cm with extremely variable upper leaves (Global Invasive Species Database 2019). It can grow up to 25-160 cm height and prefers solar radiation. It can grow fast and come into early flowering and produce enormous seeds. The seeds can germinate from September to March at optimum soil temperature and moisture (CISRO 2010). The longevity of *S. oleraceus* recorded up to 10 years under laboratory condition, whereas only 3.4-5.0% seeds were viable after 5 years in the soil. The seeds remain viable for 8 months when retained in top 2 cm, while seeds buried deeper can remain viable up to 30 months (Chauhan *et al.* 2006). Only 12% of seeds could survive after 30 months buried 10 cm deep (Widderick *et al.* 2010). At early stages up to 30 days, it does not offer serious competition; however, at 45 days onwards, it poses a serious threat. It can cause substantial yield loss to the tune of 12-45% in various crops such as chickpea, wheat, pea, *etc.* (personal observations). The major problem occurs particularly with open space field and vegetable crops. *S. oleraceus* is also an important alternate host of pest and diseases of crops *i.e.* watermelon mosaic virus, tomato spotted wilt virus and alfalfa mosaic virus, host for caster whitefly (*Trialeuro desricini*), *Bemisia* whiteflies, cotton bollworm (*Helicoverpa armigera*) (Gu *et al.* 2003) and nematode *Radopholus similis* (Schippers 2004).

It can grow in the cultivated land, field bunds, gardens, roadsides, construction sites or burned areas and degraded lands. In recent times, density of *S. oleraceus* is rapidly increasing, and it is becoming a major threat in Conservation Agriculture (CA). An urgent attention is required to develop management strategies, so that its further dissemination and losses could be minimized. Therefore, present study was conducted to understand the biology of *S. oleraceus,* assess its impact and suggest suitable management strategies to restrict its further spread in wheat and chickpea.

MATERIALS AND METHODS

Field experiments were conducted at the ICAR-Directorate of Weed Research, Jabalpur (23°132'N, 79°592'E, and 388 m above mean sea level) during 2017-18 and 2018-19 with a sub-tropical climate. The temperature ranges from 4°C in January to 45°C in May and the experimental site had a clay loam texture (Typic chromusterts) with 7.2 pH, 0.21 dS/m electrical conductivity, 0.58% organic carbon, low in available nitrogen (248 kg/ha), phosphorus (16.7 kg/ha) and exchangeable potassium 348 kg/ha) in the 0-20 cm. In a net house experiment, the seedling emergence of *S. oleraceus* from different burial depths was studied. In these, 50 counted seeds of *S. oleraceus* were placed at 0, 2, 5, 10, 15 and 20 cm burial depths and replicated thrice. In these, 0-15 cm burial depths were managed in the pots with 17 x 17 cm dimension and 30 x 28 cm dimension pots were used for 20 cm burial depths. The pots were filled with autoclaved soils of above mentioned properties. Pots were irrigated as and when required. The seedling emerged at 30 DAS were considered as final seedling emergence.

Field experiments were executed in a randomized block design with three replications, where wheat cv '*GW 273*' and chickpea cv '*JG 130*' were sown in gross plot of 5 x 5 m plot size with recommended package of practice except weed management. Pendimethalin *fb* metsulfuron 678 *fb* 4 g/ha, metribuzin + clodinafop 210 +60 g/ha, clodinafop + metsulfuron 60+4 g/ha, mesosulfuron + iodosulfuron 12+2.4 g/ha, metsulfuron-methyl 4 g/ha, control in wheat; Pendimethalin 678 g/ha, pendimethalin + imazethapyr 900+60 g/ha, imazethapyr 30 g/ha, propaquizafop + imazethapyr 50+75 g/ha, topramezone 30 g/ha, sodium acifluorfen+ clodinafop 41.25+20 g/ha, control in chickpea. The herbicides were applied as per the schedule using flat fan nozzle using 500 L/ha spray volume for pre-emergence herbicides and 375 L/ha for post-emergence herbicides. Density and biomass of *S. oleraceus* were recorded at 60 days after sowing (DAS) with standard protocol (Choudhary and Dixit 2018). The rest of the weeds emerged with crops under experiments were neither removed nor considered for the interpretation, as the densities were fewer. Observations were made on various stage of *S. oleraceus* plants *i.e.* seedling (a), leaf orientation (b) and variability in leaves (c), flower (d), puffball (e) and seeds (f) (**Figure 1a-f**). Analysis of variance was performed to determine treatment effect using SAS 9.2 (SAS Institute, Cary, NC) and significance of the treatment was determined by the *F*-test. The difference between means of two treatments was tested using least significant difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Emergence from soil burial depths

Data presented in figure 2 clearly illustrated that 33 seeds could emerged from soil surface (0 cm) followed by 7 seedlings at 2 cm depth. Further, at deeper depths (5 cm onwards), no emergence has been recorded (**Figure 1g**). It was visualized that freshly shed seeds display no dormancy and thus readily germinated at optimum soil moisture content. In CA, due to zero-till system, a large number of seeds remain on the soil surface resulting in higher seedling emergence and heavy infestation in field but at the same time it was killed by the post-emergence herbicide (clodinafop + metsulfuron 60+4 g/ha) in wheat (**Figure h-j**). These plants are well established and compete with crops for available resources in wider row spacing (Johnson and Hovestad 2002). Availability of moisture flourishes its growth and development, whereas dry condition suppresses. Light is most essential for germination, thus mulching or seeds buried in deeper soil profile inhibits seed germination and also causes high seedling mortality (Choudhary 2019).

Wheat

The lowest density (2 no/m^2) and biomass (0.5 g/m^2) of *S. oleraceus* were recorded with the application of pendimethalin *fb* metsulfuron (678 *fb* 4 g/ha) followed by clodinafop + metsulfuron (60+4 g/ha); however, both were statistically comparable. The highest density and biomass (12 no./m^2 and 6.5 g/m^2, respectively) of *S. oleraceus* were recorded in control plots. Fewer density and lighter biomass helped in achieving significantly higher weed control efficiency (WCE) in pendimethalin *fb* metsulfuron by 92.3% followed by clodinafop + metsulfuron (87.9%) (**Table 1**). Rest of the treatments recorded a significant reduction in density and biomass of *S. oleraceus* with better WCE, yet their performance was less pronounced as compared to pendimethalin *fb* metsulfuron and clodinafop + metsulfuron. The highest grain yield of wheat (4.88-5.32 t/ha) was obtained with clodinafop + metsulfuron followed by pendimethalin *fb* metsulfuron (4.87-5.22 t/ha). The lowest grain yield (3.24-3.46 t/ha) was recorded in control. The rest of weed control treatments also recorded considerably higher yield than control but were less of clodinafop + metsulfuron. In general, the density and biomass of *S. oleraceus* was more in 2018-19 then 2017-18.

Figure 1. ***Sonchus oleraceus*** **a) seedling, b) leaf orientation, c) leaves (bottom to top), d) flower, e) pappus (puffball), f) seeds, g) emergence from different burial depth , h) effect of herbicide, i) heavy infestation in wheat and j) comparison of treated and infested wheat plots**

Table 1. Effect of herbicides on density, biomass and control efficiency of *S. oleraceus* in wheat (mean of two years)

Treatment	Dose (g/ha)	Application time (DAS)	*S. oleraceus* density (no./m^2)	*S. oleraceus* biomass (g/m^2)	*Sonchus* control efficiency (%)	Wheat grain yield (t/ha)	
						2017-18	2018-19
Pendimethalin *fb* metsulfuron	678 *fb* 4	1 and 25	2	0.5	92.3	5.22	4.87
Metribuzin + clodinafop	210 +60	25	6	2.2	66.2	4.70	4.34
Clodinafop + metsulfuron	60+4	25	2	0.7	87.9	5.32	4.88
Mesosulfuron + iodosulfuron	12+2.4	25	5	2.0	69.2	4.94	4.58
Metsulfuron-methyl	4	25	4	1.3	80.0	4.79	4.35
Control	-	-	12	6.5	-	3.46	3.24
LSD (p=0.05)			2.2	0.7		0.19	0.15

Table 2. Effect of herbicides on density, biomass and control efficiency of *S. oleraceus* in chickpea (mean of two years)

Treatment	Dose (g/ha)	Application time (DAS)	*S. oleraceus* density (no./m^2)	*S. oleraceus* biomass (g/m^2)	*Sonchus* control efficiency (%)	Chickpea seed yield (t/ha)	
						2017-18	2018-19
Pendimethalin	678	1	5	2.4	71.4	2.12	1.74
Pendimethalin + imazethapyr	900+60	1	3	1.1	86.9	2.45	2.05
Imazethapyr	30	20	10	5.4	35.7	1.52	1.32
Propaquizafop + imazethapyr	50+75	20	3	1.8	78.6	2.15	1.81
Topramezone	30	20	5	3.1	63.1	2.32	2.04
Sodium acifluorfen+ clodinafop	41.25+20	20	8	4.8	42.9	1.98	1.62
Control			16	8.4	-	1.01	0.65
LSD (p=0.05)			2.5	0.8		0.12	0.09

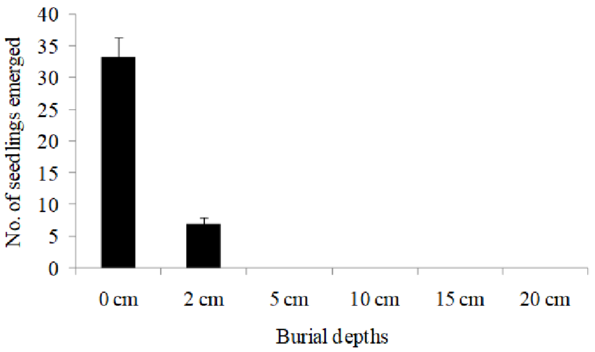

Figure 2. *Sonchus oleraceus* seedling emergence at various burial depths of soil

Chickpea

The lowest density (3 no./m^2) and biomass (1.1 no./m^2) of *S. oleraceus* was recorded with pendimethalin + imazethapyr (900+60 g/ha), whereas density was on par to propaquizafop + imazethapyr (50+75 g/ha) but biomass was considerably lower. The lesser accumulation of biomass led to achieving the highest WCE 86.9 and 78.6%, respectively (**Table 2**). Other management practices like pendimethalin, imazethapyr, topramezone, sodium acifluorfen + clodinafop also considerably reduced the density and biomass of *S. oleraceus* resulting in improved WCE, yet their response was less in relation to pendimethalin + imazethapyr. The highest seed yield (2.05-2.45 t/ha) recorded in pendimethalin + imazethapyr followed by topramezone (2.04-2.32 t/ha). The lowest seed yield (0.65-1.01 t/ha) of chickpea recorded in control. Rest of the weed management practices also provided considerably good yield than control but were less of pendimethalin + imazethapyr.

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Indian Journal of Weed Science **53**(2): 146–152, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Pearl millet-cowpea intercrop effect on *Striga hermonthica* and grain yield

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Article information

DOI: 10.5958/0974-8164.2021.00027.7

Type of article: Research article

Received : 5 November 2020
Revised : 6 May 2021
Accepted : 9 May 2021

Key words

Pearl millet varieties

Cowpea

Cropping systems

Intercrop

Striga hermonthica

Grain yield

Land equivalent ratio

ABSTRACT

Field experiment was conducted in naturally *Striga hermonthica* (Witchweed) infested field in the Kassena-Nankana East district of the upper East region, Ghana during the 2018 cropping season. This was to investigate effects of *Striga* tolerant pearl millet varieties intercropped with cowpea on *S. hermonthica* and crop yield. The study was done in a 4 x 3 factorial experiment consisting of four pearl millet varieties (*Akad-kom*, *Kaanati*, *Naad-kohblug* and *Waapp-naara*) and three cropping patterns (sole millet, millet-cowpea (1:1) and millet-cowpea (2:1) laid out in a randomized complete block design with three replications. Results showed that *Striga* emergence and shoot biomass was highest with *Waapp-naara* variety, which led to low grain yields (1.78 t/ha). Grain yield of *Akad-kom* (1.89 t/ha) was outstanding with millet-cowpea (1:1) as the best cropping pattern. Millet-cowpea (1:1) cropping pattern had the lowest *Striga* numbers and shoot biomass. *Naad-kohblug* variety and MC (1:1) cropping pattern gave best total LER of 1.44 and 1.41, respectively. Grain yield negatively correlated with *Striga* count (r = -0.42). Millet-cowpea (1:1) cropping pattern exhibited suicidal germination of *Striga* seeds, enhanced soil fertility and promoted *Striga* seed bank depletion of 46%. Resource poor farmers in *Striga* endemic areas could plant *Akad-kom* and *Naad-kohblug* varieties as sole crops or intercropped with cowpea (1:1) to manage *Striga hermonthica* and maximize grain yields.

INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Brown) is a major cereal grown primarily in Africa and Asia in tropical semi-arid regions of the world (Vanisha *et al.* 2011). It ranks after maize, rice and sorghum as the fourth most significant tropical cereal crop in the world (FAOSTAT 2015). It is particularly crucial in marginal agricultural cultivation areas in sub-Saharan Africa where it offers food, feed and fodder to millions of individuals and animals (Angarawai *et al.* 2008, Nambiar *et al.* 2011). India and Africa are the most important producers with more than 85% of the world's production (FAOSTAT 2015). In the Sahelian and Sudan Savannah regions, where an average annual rainfall ranges from 650 to 1200 mm, pearl millet is mainly produced as a rainfed cereal crop. Although the crop is indigenous and exceptionally adapted to the region, yields are generally less than 1.0 t/ha (FAOSTAT, 2016). It is the least researched crop in terms of improvement despite its importance as a food security crop in northern Ghana (Dawud *et al.* 2017).

Factors responsible for low yield include heavy infestation by parasitic weed *Striga hermonthica* (Del.) Benth (Dawud *et al* 2017, Fadelmola *et al* 2014). *S. hermonthica* is a major biotic problem to pearl millet cultivation particularly in northern Ghana, adversely affecting the livelihood of people, especially subsistence farmers, and aggravating food insecurity and poverty (Dawud *et al* 2017, Pennisi 2010, Ayman *et al.* 2014). The weed has also forced farmers to abandon their land (Atera *et al.* 2012). Hence, the control of *Striga* is an important factor in ensuring food security in these regions (Ejeta and Gressel 2007, Rodenburg *et al.* 2006). A diverse array of control approaches such as use of trap crops, resistant/tolerant varieties as well as cultural measures aimed at improving soil fertility has been used (Teka 2014). Although these methods have helped in reducing the impact of this pernicious weed, they have not addressed the *Striga* seed problem effectively (Ransom 2000). Thus, the extensive seed bank of *Striga* in infested fields remains an impediment (Parker 2012).

Intercropping millet and cowpea can suppress the germination of *S. hermonthica*, improve soil fertility, reduce the level of inorganic fertilizer requirement and reduce *Striga* seed bank (Sunda 2014). Farmers have attempted to intercrop *Striga* tolerant millet varieties with cowpea in the Sudan Savanna, but there is little information on its efficacy in reducing *Striga* infestation, as well as increasing productivity. Resistance is often regional and performance depends on environmental conditions. Also, information on performance of tolerant varieties screened under *S. hermonthica* susceptible areas in the Sudan Savannah region of Ghana is lacking. The study seeks to evaluate the effects of intercropping locally developed *Striga* tolerant pearl millet and cowpea on *S. hermonthica* management and pearl millet yield.

MATERIALS AND METHODS

Field study was conducted at Saabisi-Natugnia in the Kassena-Nankana East District (latitude 100 45' N and Longitude 010 06' W) in the Upper East Region of Ghana during the 2018 cropping season. The vegetation of the site is grassland regrowth with short trees, shrubs and thumps. The climate is warm, Semi-arid with average total annual monomial rainfall of 950 mm. Day temperatures are high recording 42° Celsius (especially between February and March) and night temperatures could be as low as 18° Celsius. The soil in the study area has been described as Savannah ochrosols with Aeolian Sandy loam (IUSS World Reference Base 2006). Cumulative precipitation during the crop growing season at the experimental site was 980.4 mm.

The study was done in a 4 × 3 factorial laid in a randomized complete block design (RCBD) and replicated thrice. A factorial treatment combination consisting of four pearl millet varieties (*Akad-kom*, *Kaanati*, *Naad-kohblug* and *Waapp-naara*) and three cropping patterns (Sole millet, one row of millet: one row of cowpea (1:1) and two rows of millet: one row of cowpea (2:1) were used. Additional plot was created under each replication to enable calculation of land equivalent ratio (LER). There were thirteen (13) plots in each replication measuring 5 x 5 m (25 m^2) with total plot size of 1,587 m^2. An alley of 1.5 m between blocks and 1.0 m between plots was used for easy movement of materials and agronomic operations.

The local photoperiod sensitive medium maturing spreading cowpea type "*Padituya*" from farmers was used. Each of the millet variety was planted at a planting distance of 0.75 × 0.3 m (0.225 m^2) and row length of 5 m (approximately 7 stands per row). A maximum of five seeds per hole and seedlings thinned to two per hole two weeks after emergence. Cowpea was planted three seeds per hole and thinned to two at a spacing of 0.75 × 0.2 m (0.15 $m^{2)}$ and row length of 5 m (approximately 7 stands per row). In sole and intercrop, millet and cowpea were sown at a depth of 3 cm on the same day. Empty hills were refilled. The plots were hoe-weeded at 2 and 5 weeks after planting. Number of emerged *Striga* plants per plot was counted at 8, 10, 12 and 14 weeks after the appearance of the first *Striga* plant in the field. The *Striga* were uprooted at each *Striga* count and weight was taken. The parasites were then packed in envelopes and dried for 48 hours at 80 ^oC and dry weight recorded using electronic scale.

For determination of *Striga* seed bank, soil samples were taken randomly from each plot and thoroughly mixed to achieve a composite sample. *Striga* count determination was done using potassium carbonate separation method as described by Berner *et al.* (1997). Average *Striga* counts were also determined for each plots after harvest.

Grain and biomass yield: The grain yield per plot for each treatment was determined from two middle rows with an area of 7.1 m^2. Grain yield was estimated using a measurement scale to weigh the grain yield per plot after drying the panicles in the sun to about 10% moisture content, threshing, winnowing, and cleaning. Using the formula (10000 x yield per plot)/ (plot size x 1000), the grain yield per plot was converted to kg/ha. Pearl millet stalks were cut near the soil surface and their total fresh weight taken. A sub-sample was thereafter taken from the total stalks in each plot, weighed and recorded. The sub-sample was thereafter dried and weighed. The weights for both were used to calculate the pearl millet biomass.

At physiological maturity, millet plants were manually harvested from an area of 7.1 m2 (4 ´ 3.3 m) per plot. Grains were threshed, winnowed and cleaned. They were weighed, converted to grain yield, and reported in ton per hectare. The above ground biomass and grain yield were determined on a dry-weight basis by oven drying the crop samples at 105°C for 45 min and subsequently to constant weight at 85°C.

Land equivalent ratio

The competition function was calculated to analyze the impacts of competition between plants and to assess intercrop efficiency and land equivalent ratio (LER). The LER is a precise evaluation of the intercropping situation's biological effectiveness was calculated as outlined by Alhassan and Egbe (2014):

LER = LERim+LERsm ……..1

LER= Yim/Ysm ………......................…………………….2

LER = Yic/Ysc ………….....………………………………….3

Where the subscript letters, m and c stand for pearl millet and cowpea, respectively; Yim and Ysm are yields of pearl millet intercrop and sole crop while Yic and Ysc represent yields of cowpea intercrop and sole crop. LER value above one indicates an advantage of intercropping over sole cropping while LER value below one shows that there is no advantage by intercropping.

Statistical analysis

Data collected were subjected to Analysis of Variance (ANOVA) using GENSTAT statistical software version 12. Significant differences among treatments were determined using Least Significance Difference (LSD) at 5% level of probability. All count data (*i.e., Striga* count) were transformed logarithmically (Kihara *et al.* 2011) before being subjected to ANOVA to reduce variation in the results. Linear correlation coefficients were also calculated to determine the degree of association among the pearl millet agronomic parameters and *Striga* counts.

RESULTS AND DISCUSSION

Effect on *Striga*

Composite soil samples taken at separate depths from the site before the beginning of the experiment varied with 0-10 cm recording the highest number of *Striga* counts compared to 10-20 cm (**Table 1**). *Striga* seeds were least (195) in the 10-20 cm soil depth compared to 359 in 0-10 cm depth. The high *Striga* seed count in the 0-10 cm depth could be due to method of dissemination (Woomer and Savala 2008) which usually happens on top soil resulting to an increase in *Striga* seed bank. Weber *et al.* (1995) reported several thousand *Striga* seeds close to the surface of the soil, but less as soil depth increases.

Striga attack incidence and severity depends on *Striga* susceptibility of the host (Esilaba 2008). Increased *Striga* emergence in *Waapp-naara* variety may be due to its susceptibility to the parasitic weed (Fasil and Verkleij 2007). Rodenburg *et al.* (2006) also reported fewer *Striga* emergence in resistant crops compared to non-resistant crops. The low *Striga* emergence in *Kaanati, Akad-kom,* and *Naad-kohblug* intercropped with cowpea in the MC (1:1) cropping pattern may be attributed to reduced *Striga* germination or reduced attachment of germinated *Striga* to host plant roots as a result of interactive effect between variety and intercropping. These observations corroborate earlier reports by Kureh *et al.* (2006), who reported that *S. hermonthica* density is significantly suppressed when cereals are intercropped with legumes. Cowpea inclusion might have suppressed both emergence and development of *S. hermonthica*, which improved the productivity of the pearl millet component in the system. The presence of cowpea also might have suppressed *Striga* plant growth and development, which reduced *Striga* biomass compared to sole pearl millet.

Table 1. Initial average *Striga* counts at Saabisi

Soil depth (cm)	*STRIGA* COUNT Seeds/100g soil				
	1st SET	2nd SET	3rd SET	4th SET	Average count
0-10	367	354	357	358	359
10-20	195	190	196	199	195

The best sustainable control of *Striga* should be the depletion of *Striga's* vast, long-lived seed bank (Zwanenburg *et al.* 2016). Reduced percentage *Striga* seed bank by variety (31.4 to 42.7%) and cropping pattern (37.6 to 46.2%) may be attributed to induced germination of *S. hermonthica* by host-plant resistance varieties and trap crop (cowpea), respectively. Dugje and Ngala (2012) reported that the level of *Striga hermonthica* infestation of sole millet was significantly higher than millet intercropped with cowpea. De Groote *et al.* (2010) recorded *Striga* suicidal germination and decreased seed bank of *Striga* in intercrop of maize and soybean. Dawud *et al.* (2017) also recorded parasite seed bank depletion with trap crop, thereby reducing harm to cereal crops. Interaction between *Kaanati* and *Akad-kom* varieties and the MC (1:1) cropping pattern reduced percentage *Striga* seed bank by 42% - 46%. The decreased number of *Striga* seed banks can be attributed to germination stimulant by the cowpea (Padituya) roots resulting to suicidal germination. This agrees with De Groote *et al.* (2010) and who observed that the use of trap crop such as soybean triggers suicidal germination of *Striga* and therefore reduces the *Striga* seed bank in the soil when intercropped with maize. Result from the present study indicates that *Striga* tolerant pearl millet varieties can help reduce *Striga* soil seed bank in *Striga* endemic areas as more will germinate but its growth and development will not be supported.

Interaction between pearl millet varieties and intercropping significantly influenced ($p<0.05$) *Striga* count at 8, 10 and 12 WAP (**Table 2**). *Waapp-naara* significantly increased *Striga* emergence count with a mean of 4.40, 4.85 and 7.47 at 8, 10 and 12 WAP, respectively compared to other treatment. At week 10 and 12, *Naad-kohblug* gave the least mean *Striga* seedling emergence/plot of 1.74 and 1.79, respectively. Among the cropping pattern, sole crop recorded the highest *Striga* count of 4.00 and 6.73 at 10 and 12 WAP, respectively with MC (1:1) treatment recording the lower of 1.71 and 2.63 at 10 and 12 WAP, respectively. For *Striga* biomass production, MC (2:1) gave the highest (2.00 kg/ha), followed by sole crop (1.99 kg/ha) and MC (1:1) 1.19 kg/ha at 8 WAP.

Percentage reduction in *Striga* soil seed bank were significantly affected by variety cropping pattern interaction. Percentage *Striga* soil seed bank reduction ranged from 31.40% (*Waapp-naara*) to 42.70% (*Akad-kom*) for varieties compared to cropping pattern 37.56% (sole crop) to 46.20% (MC (1:1) (**Figure 1**).

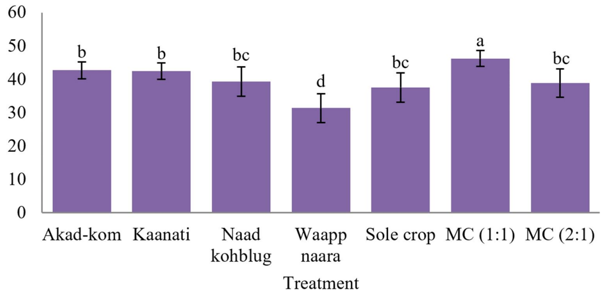

Figure 1. Per cent reduction in *Striga* soil seed bank after harvest

Effect on pearl millet

The interaction between pearl millet varieties and cropping patterns did not significantly (P>0.05) affect the panicle length and girth of pearl millet. However, variety significantly (P<0.05) influenced panicle length and girth. *Naad-kohblug* produced the highest (31.07 cm, 11.12cm) panicle length and girth, respectively while *Akad-kom* produced the lowest (12.38 cm, 7.11 cm) as shown in **Table 3**.

Table 2. Effects of pearl millet varieties and cropping patterns on *Striga* count and biomass production

Treatment	*Striga* count (√x + 0.5)				*Striga* biomass (kg/ha)			
	8 WAP	10 WAP	12 WAP	14 WAP	8 WAP	10 WAP	12 WAP	14 WAP
Variety								
Akad-kom	2.27	2.57	4.00	1.75	1.46	1.71	2.39	1.18
Kaanati	2.25	3.06	4.52	1.15	1.40	2.02	2.61	0.91
Naad-kohblug	2.68	1.74	1.79	1.07	1.65	1.30	1.26	1.30
Waapp-naara	4.40	4.85	7.47	2.59	2.40	3.13	4.56	1.80
LSD (p=0.05)	1.48	1.66	1.96	1.57	0.70	0.95	1.12	0.84
Cropping pattern								
Sole crop	3.49	4.00	6.73	1.87	1.99	2.65	4.06	1.32
MC (1:1)	1.72	1.71	2.63	1.86	1.19	1.22	1.76	1.27
MC (2:1)	3.50	3.45	3.97	1.69	2.00	2.25	2.28	1.32
V * CP	2.56	2.87	3.39	NS	NS	1.64	1.94	NS
LSD (p=0.05)	1.28	1.44	1.69	1.35	0.60	0.82	0.97	0.73

NS = No significant difference; WAP- Weeks after planting

Table 3. Effects of pearl millet varieties and cropping patterns on yield components and grain yield of millet

Treatment	Panicle		Productive tiller count		Yield	
	Length (cm)	Girth (cm)	7 WAP	9 WAP	Grain yield (t/ha)	Stover yield (t/ha)
Variety						
Akad-kom	12.38	11.12	1.49	1.68	1.89	2.60
Kaanati	27.44	7.11	1.33	1.36	1.82	2.00
Naad-kohblug	31.07	8.08	1.15	1.68	1.89	3.30
Waapp-naara	22.91	9.08	0.74	1.70	1.78	2.33
LSD (p=0.05)	0.83	0.16	0.35	0.31	0.06	0.24
Cropping pattern						
Sole crop	23.55	8.82	1.22	1.73	1.83	2.26
MC (1:1)	23.44	8.87	1.09	1.40	1.89	2.66
MC (2:1)	23.36	8.86	1.22	1.68	1.79	2.76
V * CP	NS	NS	NS	NS	NS	NS
LSD (p=0.05)	0.71	0.14	0.30	0.27	0.06	0.21

NS = No significant difference; WAP- Weeks after planting

The main effect of pearl millet variety significantly affected number of productive tiller counts at 7 WAP. *Akad-kom* treatment recorded the highest (1.49 per/plant) number of productive tiller counts than *Kaanati*, *Naad-kohblug* and *Waapp-naara* treatments at 7 WAP.

The interaction between pearl millet varieties and cropping patterns did not significantly (P>0.05) influence grain yield. However, variety was significantly (p<0.05) different with *Akad-kom* recording the greatest (1892.00 kg/ha) while *Waapp-naara* the least (1778.00 kg/ha).

The MC (1:1) cropping pattern significantly increased grain yield by 5% compared to MC (2:1). Stover yield significantly differed (p<0.05) among pearl millet varieties with *Naad-kohblug* producing the highest Stover yield (3300 kg/ha) and *Kaanati* least (2000 kg/ha). The interaction between pearl millet varieties and cropping patterns did not significantly (P>0.05) affect stover yield.

Kaanati, Akad-kom and *Naad-kohblug* with MC (1:1) cropping pattern were identified with low *Striga* emergence and with good agronomic performance in this study. This indicates that these genotypes based on phenotypic data were more resistant/tolerant to *Striga* infestation. *Waapp-naara* variety on the other hand supported *Striga* emergence and biomass production resulting to a significantly lower grain yield.

There were significant negative correlations between *Striga* parameters (*Striga* counts and biomass) measured and yield (stover and grain yield). For example, grain yield negatively correlated with *Striga* emergence (r = -0.42). This is an indication that yield was significantly reduced by *Striga* infestation. Mesfin (2016), Ezeaku *et al.* (2015), and Kanampiu *et al* (2018) found similar results in pearl millet. This result is in line with the findings of Kim (1997), who reported significant and negative correlation between maize grain yield and *Striga* emergence. *Akad-kom and Naad-kohblug* varieties respectively recorded greater productive tiller numbers in the present study. These could be the contributing characters for high grain yield. Pearl millet varieties that showed greater tiller numbers and low *Striga* counts might be indicative of genotypes that are less prone to *Striga* infestation. Between *Striga* count and productive tiller count there was a significant negative correlation (r = -0.01).

Land equivalent ratio

Land equivalent ratio was significantly (p<0.05) affected by intercropping (**Table 4**). The highest land equivalent ratio value of 1.44 was recorded on *Naad-kohblug* variety and the lowest land equivalent ratio value of 1.24 was recorded on *Waapp-naara* variety. All other treatment means were statistically similar. The MC (1:1) gave the highest (1.41) land equivalent ratio and this was significantly (p<0.05) greater than the MC (2:1) cropping pattern (1.25). Intercropping systems had total LER values higher than the sole meaning intercropping was more efficient than the sole cropping (Jackson 2009). Crop differ in the way they use environmental resources and complement each other and make better use of resources when they grow together than when they are grown separately (Long *et al.*, 2011). Partial LER revealed that *Naad-kohblug* variety and MC (1:1) cropping pattern were more productive. *Naad-kohblug* and MC (1:1) cropping pattern resulted to greater LER of 1.44 and 1.41, respectively. Abera *et al.* (2005) also observed that, in terms of food production per unit area, the LER values ranged from 1.15 to 1.42 suggesting higher productivity and land use effectiveness of intercropping.

Table 4. Effects of pearl millet-cowpea on partial land equivalent ratio of cowpea (PLERc), partial land equivalent ratio of pearl millet (PLERm) and land equivalent ratio (LER)

Treatment	Partial land equivalent ratio of cowpea	Partial land equivalent ratio of pearl millet	Land equivalen ratio
Variety			
Akad-kom	0.43	0.88	1.31
Kaanati	0.52	0.78	1.30
Naad-kohblug	0.59	0.85	1.44
Waapp-naara	0.42	0.82	1.24
LSD (p=0.05)	0.09	0.15	0.13
Cropping pattern			
MC (1:1)	0.57	0.84	1.41
MC (2:1)	0.42	0.83	1.25
LSD (p=0.05)	0.07	0.11	0.09
CV (%)	15.7	15.2	7.90
V * CP	NS	0.22	0.18

NS = No significance difference

Pearl millet grain yield negatively correlated with *Striga* count (r = -0.42) and 1000 grain weight (r = -0.59) (**Table 5**). However, grain yield positively correlated with number of tiller count/plant, panicle girth and panicle weight/plant (r = 0.13 to 0.40). *Striga* biomass negatively correlated with panicle length, stover yield, grain yield and 1000-grain weight (**Table 5**).

Conclusion

Pearl millet varieties and cropping patterns have proved to manage *Striga* by reducing *Striga*

Table 5. Relationships between pearl millet agronomic parameters and *Striga* counts

Parameter	1	2	3	4	5	6	7	8	9	10
Cumulative *Striga* count	-									
Striga biomass (kg/ha)	0.95***	-								
Tiller count	0.40**	0.39**	-							
Productive tiller count	-0.01	0.05	0.25*	-						
Panicle length (cm)	-0.04	-0.07	-0.17	-0.23*	-					
Panicle girth (cm)	0.05	0.05	0.29*	0.23*	-0.91***	-				
Panicle weight (g)	0.13	0.09	0.05	-0.02	0.36**	-0.31*	-			
Stover yield (kg/ha)	-0.19	-0.24*	-0.04	-0.02	0.36**	-0.03	0.17	-		
Grain weight (g)	-0.59***	-0.46**	-0.19	0.28*	0.16	-0.11	-0.13	0.15	-	
Grain yield (kg/ha)	-0.42**	-0.39**	-0.06	-0.04	0.04	0.07	-0.28*	0.24*	0.48**	-

* = significant (p=0.05), ** = significant (p= 0.01), *** = significant (p=0.001). Values without asterisk(s) have no significant linear correlation

emergence, seed bank and *Striga* biomass resulting to improved grain yield and land equivalent ratios greater than one (LER > 1). *Striga* tolerance pearl millet varieties (*Akad-kom* and *Naad-kohblug*) are recommended in *Striga* infested field in the Sudan Savannah for reduced *Striga* seed bank and improved millet yield. For improved yield and best land productivity or LER, small holder farmers could plant *Naad-kohblug* using MC (1:1) cropping pattern.

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Indian Journal of Weed Science **53**(2): 153–157, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Bio-efficacy of ready-mix sodium acifluorfen + clodinafop-propargyl for weed management in groundnut

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Article information

DOI: 10.5958/0974-8164.2021.00028.9

Type of article: Research article

Received : 26 September 2020
Revised : 31 May 2021
Accepted : 3 June 2021

Key words

Clodinafop-propargyl, Groundnut, Sodium acifluorfen, Weed density, Yield

ABSTRACT

Field experiments were conducted to evaluate the bio-efficacy and phyto-toxicity of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC as post-emergence against weed flora in groundnut during *Kharif* (rainy season) 2015 and summer 2016 at UAS, GKVK, Bengaluru, Karnataka. Different post-emergence herbicides were applied at 22 days after sowing (DAS) and compared with two rounds of hand weeding at 20 and 45 DAS. The results revealed that sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC (206.25 + 80 g/ha) recorded higher pod (1.44 and 1.65 t/ha) and haulm yield (1.59 and 1.89 t/ha) in 2015 and 2016. Higher economic yield under this treatment was attributed to the reduced weed density, weed dry weight, weed index and higher weed control efficiency and higher herbicide efficiency index. Post-emergence application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC was found non-phytotoxic to groundnut as well as succeeding crop (finger millet).

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop in India, occupying an area of 4.81 million hectares with a production of 6.69 million tonnes (GoI 2020). It is grown throughout the year during *Kharif* (rainfed), *Rabi* (winter) (residual moisture), summer (irrigated) and spring (irrigated) seasons although nearly 80% of total groundnut area is covered during *Kharif*. Productivity of groundnut in India is lower than the world average. Weed menace is considered as one of the major production constraints (Chaitanya *et al*. 2012). Weeds emerge fast, grow rapidly, and lead to severe competition with crop plants for different growth resources like nutrients, sunlight, space and soil moisture. In India, yield losses in groundnut due to weeds range from 17 to 96% (FAO 2002). In groundnut, the critical stage of crop-weed competition is around 25-35 days after sowing, cultural practices of weed control does not ensure the weed free environment to the crop for the longer time, so timely PoE application of herbicide ensures weed free environment during critical stage of crop-weed competition and later stages of the crop. Controlling weeds by hand or intercultural operation does not ensure weed-free environment to the rainfed crop, rather it involves higher cost of cultivation and often becomes ineffective during *Kharif* because of incessant rains with adverse field conditions, causing hindrance to enter into the field. Weed management through conventional hand weeding in irrigated summer crop is also cost-prohibitive. With this background in view, the present investigation was undertaken to develop an effective recommendation on weed management with the use of post-emergence (PoE) herbicides for yield enhancement in both rainfed and irrigated groundnut.

MATERIALS AND METHODS

Field experiments were conducted during *Kharif* and summer seasons of 2015-16 at the Eastern Dry Zone of Karnataka which is located between 13^0 52' 183'' N Latitude and 77^0 332' 583'' Longitude, Gandhi Krishi Vignan Kendra, University of Agricultural Sciences, Bengaluru, Karnataka, India. Groundnut variety '*ICGV-91114*' was sown at a spacing of 30 × 10 cm during *Kharif* (rainy season) 2015 which was sown on 07-07-2015 and harvested on 10-11-2015, the available N, P and K were 253, 32 and 260 kg/ha, respectively at harvest and summer crop was (2016) sown on 20-12-2015 and harvested on 02-05-2016, N, P, K were 259, 32.4 and 269 kg/ha, respectively at harvest. The recommended dose 25:50:25 kg NPK/ha application for seasons as rainfed and irrigated crop, respectively. Eight treatments were assigned in a randomized complete block design with three replications. The treatments included sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC (123.75 + 60, 165 + 80 and 206.25 + 80 g/ha) as post-emergence (PoE), sodium acifluorfen 20% SL (165 g/ha) as PoE, clodinafop-propargyl 15% WP (80 g/ha) as PoE, imazethapyr 10% SL (150 g/ha) as PoE, hand weeding (twice) at 20 and 45 days after sowing (DAS), and weedy check (untreated). Herbicides were applied at a spray volume of 500 litres of water/ha at 22 DAS, using knapsack sprayer fitted with flat fan nozzle.

Weed counts were taken in a quadrat of 50 × 50 cm at 20, 45, 60 DAS and harvest, and expressed as weed density (no./m^2). Category–wise dry weights (g/m^2) of weeds (sedges, grasses and broad-leaved) were also recorded at 20, 45, 60 DAS and at harvest. Data on weed density and weed dry weight were analyzed using ($\sqrt{x+1}$) square root transformation. Weed control efficiency (WCE) of different treatments were calculated. Per cent weed infestation of different weed categories, *i.e* sedges, grasses and broad-leaved weeds were also calculated for different treatments. Data on seed yield, haulm yield and weed index were recorded at harvest. Herbicide efficiency index (HEI) and weed management index (WMI) were calculated as per the formula suggested by Krishnamurthy *et al*. (1975) and Walia (2003), respectively.

$$\text{HEI} = \frac{\text{Yield of treated plot} - \text{Yield in control}}{\text{Yield in control}}$$

$$\text{WCE} = \frac{\text{Weed dry weight in control} - \text{Weed dry weight in treated}}{\text{Weed dry weight in control}} \times 100$$

After the harvest of the groundnut crop, the residual crop Finger millet was grown to know the phytotoxicity effect on succeeding crop.

RESULTS AND DISCUSSION

Weed flora

The experimental field was mostly infested with grasses (61.18%), followed by broad-leaved weeds (32.91%) and sedges (5.98%) in both seasons. Major weeds in the experimental field in both the seasons were *Cyperus rotundus* (sedges from initial stages), *Eleusine indica*, *Dactyloctenium aegyptium* (from initial stages), and *Echinochloa colona* (from 30 days onwards). Broad-leaved weeds were *Alternanthara sessilis*, *Commelina benghalensis*, *Borreria articularis*, *Cleome viscosa*, *Euphorbia geniculata*. Other weeds as observed in lesser number were *Amaranthus viridis*, *Cleome monophyla* and *Acanthospermum hispidum*. Similar weed species associated with groundnut crop were reported by Mudalagiriyappa *et al*. (2001) and Sathya Priya *et al*. (2017).

Effect on weeds

All the weed management practices recorded significantly lower weed density than that of weedy check at different stages of crop growth (**Table 1**). Before application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC at different doses, *viz.* 123.75 + 60, 165 + 80, and 206.25 + 100, the respective plots recorded weed densities of 47.2, 47.1 and 41.0/m^2 in 2015 and 59, 52.9 and 56.4/m^2 in 2016 at 20 DAS. At 45 DAS, post-emergence application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC at 123.75 + 60 g/ha recorded lower weed density (19.8/m^2), followed by same herbicidal combination at 165 + 80 and 123.75 + 60 g/ha (31.6 and 31.8/m^2) as compared to the weedy check (69.6/m^2). Similar trend of treatment effect on weed density was recorded at 60 DAS and harvest **(Table 1)**. Lower weed densities under these treatments were attributed to effective control of weeds at later stages of crop growth with the PoE application of sodium acifluorfen 16.5% and clodinafop-propargyl 8% EC. These results corroborated the findings of Jha *et al*. (2014). The weed density could significantly be lowered down with hand weeding due to manual removal of all the weeds (Wani *et al*. 2010).

There were no significant differences in weed dry weights at 20 DAS due to non-imposition of treatments (**Table 2**). At 45 and 60 DAS, application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC at 206.5 + 100 g/ha recorded lower weed dry weight (2.39 and 2.13 g/m^2, respectively) which remained statistically on par with the same herbicide applied at 165+80 g/ha, whereas maximum weed dry weight was recorded in the weedy check (3.84 and 4.49 g/m^2, respectively). Similar results were recorded in year 2016. Reduced weed dry weight with PoE application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC was mainly due to effective control of grasses and broad-leaved weeds throughout the crop growth stages. These results were in conformity with Choudhary *et al*. (2017).

Data on WCE at harvest showed that hand weeding (twice) recorded the highest WCE (82.99 and 90.11%), followed by sodium acifluorfen 16.5%

+ clodinafop-propargyl 8% EC applied at 206.25 + 100 g/ha (87.41 and 90.22%) and at 165 + 80 g/ha (85.98 and 89.90%). **(Table 4)**. Improved WCE with the use of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC at higher doses was due to effective reduction in dry weight of grasses and broad-leaved weeds. These results were in confirmatory with the findings of Jha *et al.* (2014).

Effect on crop

The pod yield of groundnut differed significantly due to different weed management practices (**Table 3**). Two rounds of hand weeding recorded the highest pod yield (1.48 t/ha), which was at par with the application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC at 206.25 + 100 g/ha (1.44 t/ha) at 165 + 80 g/ha (1.41 t/ha), whereas it was the lower in the weedy check plots (0.62 t/ha). Yield advantages due to weed management with the use of PoE herbicides were reported by Singh *et al.* (2012) and Choudhary *et al.* (2017). Weed index (WI) had a direct relation with the yield reduction due to weed infestation. Lower WI was recorded under hand weeding (20 and 45 DAS), followed by PoE application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC (206.25 + 100 and 165 + 80 g/ha), whereas it was the highest under weedy check (58.45%). Reduction in yield was attributed to the higher density of weeds and dry matter production, leading to higher WI (Patel *et al.* 1997 and Jayaram 2001).

Higher herbicide efficiency index (HEI) was

Table 1. Effect of different weed management treatments on weed density (no./m²) at different stages in groundnut

Treatment	20 DAS		45 DAS		60 DAS		Harvest	
	2015	2016	2015	2016	2015	2016	2015	2016
Sodium-acifluorfen 16.5% + clodinafop-propargyl 8% EC (123.75 + 60 g/ha)	6.87 (47.2)	7.68 (59.0)	5.52 (30.5)	6.0 (36.0)	4.11 (16.9)	4.56 (20.8)	3.94 (13.9)	3.81 (14.5)
Sodium-acifluorfen 16.5% + clodinafop-propargyl 8% EC (165 + 80 g/ha)	6.73 (47.1)	7.28 (52.9)	5.18 (26.8)	5.17 (26.7)	3.95 (15.6)	4.14 (17.1)	3.70 (14.2)	3.58 (12.8)
Sodium-acifluorfen 16.5% + clodinafop-propargyl 8% EC (206.25 + 80 g/ha)	6.40 (41.0)	7.51 (56.4)	4.92 (24.2)	4.81 (23.4)	3.59 (12.9)	3.92 (13.98)	3.41 (12.9)	3.38 (11.4)
Sodium-acifluorfen 20% SL (165 g/ha)	6.30 (39.8)	7.27 (52.9)	6.67 (44.5)	7.10 (50.4)	6.95 (48.3)	7.37 (54.3)	7.24 (52.5)	7.76 (60.2)
Clodinafop-propargyl 15% WP (80 g/ha)	6.00 (36.0)	7.20 (51.9)	5.81 (33.7)	6.36 (54.2)	5.34 (28.5)	6.40 (41.0)	5.81 (54.2)	6.70 (44.9)
Imazethapyr 10% SL (150 g/ha)	5.84 (34.2)	7.22 (52.1)	5.99 (35.8)	6.72 (45.1)	6.16 (38.0)	6.82 (46.6)	6.25 (39.2)	6.97 (48.6)
Hand weeding (twice)20 and 45 DAS	6.35 (40.3)	7.46 (55.6)	4.10 (16.8)	4.56 (20.8)	3.72 (13.8)	3.47 (12.1)	4.04 (16.3)	3.40 (11.6)
Weedy check (untreated)	6.36 (40.5)	7.48 (56.0)	7.79 (60.7)	8.86 (78.6)	8.19 (67.2)	9.40 (88.3)	9.85 (97.0)	10.82 (117.1)
LSD (p=0.05)	0.49	NS	0.28	0.36	0.24	0.32	0.33	0.26

DAS: Days after sowing; Original figures in parentheses were subjected to square root transformation

Table 2. Effect of different weed management treatments on weed dry weight (g/m²) at different stages in groundnut

Treatment	20 DAS		45 DAS		60 DAS		Harvest	
	2015	2016	2015	2016	2015	2016	2015	2016
Sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC (123.75 + 60 g/ha)	3.19 (9.20)	3.51 (11.30)	2.80 (6.84)	3.10 (8.59)	2.41 (4.80)	2.54 (5.46)	2.32 (4.37)	2.02 (3.06)
Sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC (165 + 80 g/ha)	3.17 (9.03)	3.34 (10.18)	2.47 (5.08)	2.68 (6.20)	2.22 (3.92)	2.41 (4.81)	2.01 (3.16)	1.98 (2.92)
Sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC (206.25 + 80 g/ha)	3.00 (8.01)	3.44 (10.82)	2.39 (4.69)	2.51 (5.30)	2.13 (3.55)	2.25 (4.07)	1.93 (2.73)	1.88 (2.53)
Sodium acifluorfen 20% SL (165 g/ha)	2.93 (7.57)	3.34 (10.15)	3.34 (10.14)	3.62 (12.13)	4.03 (15.27)	3.91 (14.27)	3.60 (11.94)	3.78 (13.30)
Clodinafop-propargyl 15% WP (80 g/ha)	2.82 (6.94)	3.31 (9.95)	2.67 (6.11)	3.12 (8.75)	2.67 (15.27)	2.93 (7.59)	2.69 (6.21)	2.84 (13.75)
Imazethapyr 10% SL (150 g/ha)	2.75 (6.57)	3.31 (9.99)	3.03 (8.21)	3.44 (10.85)	3.57 (11.75)	3.64 (12.24)	3.15 (8.89)	3.43 (10.73)
Hand weeding 20 and 45 DAS	2.97 (7.80)	3.41 (10.66)	2.10 (3.42)	2.45 (5.00)	2.23 (3.97)	2.04 (3.17)	2.17 (3.69)	1.88 (2.56)
Weedy check (untreated)	2.96 (7.74)	3.43 (10.73)	3.84 (13.76)	4.46 (18.90)	4.49 (19.17)	4.92 (23.21)	4.76 (21.69)	5.18 (25.88)
LSD (p=0.05)	NS	0.12	0.41	0.29	0.24	0.22	0.18	0.14

DAS= Days after sowing; Data subjected to square root transformation; data with in parentheses are original values recorded under sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC at 206.25 + 100 g/ha (10.64), followed by same herbicide combination at 165 + 80 g/ha (8.83%) and 123.75 + 60 g/ha (5.70%). Higher HEI was achieved due to lower weed dry weight as well as higher pod yield with the imposition of these treatments (**Table 3**).

Weed management index (WMI) was significantly influenced by different weed management treatments (**Table 4**). Higher WMI was recorded in hand weeding at 20 and 45 DAS (1.45), which was followed by PoE application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC at 206.25 + 100 g/ha (1.37) and clodinafop-propargyl 15% WP at 80 g/ha (1.29). Similar findings were reported by Kumar *et al*. (2013) and Siddhu *et al*. (2018) in garlic.

Economics

Higher net returns and B: C ration were observed with application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% 80 EC at 206.25 + 100 g/ha ₹ 32330/ha and 2.15, respectively) and at 165 + g/ha (₹ 31570/ha and 2.14, respectively). However, two rounds of hand weeding recorded higher gross returns (₹ 62160/ha) as compared to other treatments. The lower cost of cultivation, gross returns, net returns and B:C ratio were recorded in the weedy check plots (₹ 23200/ha, ₹ 26040/ha, ₹ 2840/ha and 1.12, respectively). The similar results were obtained during 2016 (**Table 5**). The highest net returns and B:C ratio with application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% 80 EC at 206.25 + 100 g/ha was due to higher pod yield with lesser cost of weeding with herbicide application. Even though higher gross returns were recorded in two hand weeding, higher labour wages increased the cost of cultivation and lowered the B:C ratio. Similar results were reported by Kalhapure *et al.* (2013).

Growth and yield of succeeding finger millet was not affected due to imposition of weed management practices in preceding groundnut. This was in accordance with Sathya Priya and Chinnusamy (2020). The germination percentage was recorded and other physiological factors like yellowing, stunting, wilting and deformities *i.e.*,

Table 3. Effect of different weed management treatments on pod yield, haulm yield, weed index and herbicide efficiency index at harvest in groundnut

Treatment	Pod yield (t/ha)		Haulm yield (t/ha)		Weed index (%)		Herbicide efficiency index at harvest	
	2015	2016	2015	2016	2015	2016	2015	2016
Sodium acifluorfen + clodinafop-propargyl (123.75 + 60 g/ha)	1.25	1.42	1.45	1.57	16.03	17.62	5.07	6.34
Sodium acifluorfen + clodinafop-propargyl (165 + 80 g/ha)	1.41	1.62	1.55	1.78	5.19	5.81	8.80	8.86
Sodium acifluorfen + clodinafop-propargyl (206.25 + 80 g/ha)	1.44	1.65	1.59	1.89	2.69	4.07	10.66	10.61
Sodium acifluorfen 20% SL (165 g/ha)	0.86	1.05	1.11	1.31	42.29	38.95	0.71	0.58
Clodinafop-propargyl 15% WP (80 g/ha)	1.04	1.34	1.21	1.54	30.10	22.09	2.38	1.23
Imazethapyr 10% SL (150 g/ha)	0.94	1.18	1.10	1.38	36.57	31.57	1.29	1.09
Hand weeding 20 and 45 DAS	1.48	1.72	1.61	1.91	0.00	0.00	-	-
Weedy check (untreated)	0.62	0.81	0.85	1.05	58.45	52.91	-	-
LSD (p=0.05)	0.15	0.18	0.12	0.23	-	-		

Table 4. Effect of different weed management treatments on weed management index (WMI), weed infestation (%) and weed control efficiency (WCE) at harvest in groundnut

Treatment	WMI		Weed infestation (%)								WCE	
			2015				2016					
	2015	2016	Sedges	Grasses	BLWs	Total	Sedges	Grasses	BLWs	Total	2015	2016
Sodium acifluorfen + clodinafop-propargyl (123.75 + 60 g/ha)	1.19	0.85	20.14	46.04	33.81	13.9	15.86	43.45	40.69	14.5	79.85	87.94
Sodium acifluorfen + clodinafop-propargyl (165 + 80 g/ha)	1.50	1.13	17.61	41.55	40.85	14.2	15.63	42.19	42.18	12.8	85.98	89.90
Sodium acifluorfen + clodinafop-propargyl (206.25 + 80 g/ha)	1.54	1.20	17.83	39.53	32.56	12.9	17.54	38.60	43.86	11.4	87.41	90.22
Sodium acifluorfen 20% SL (165 g/ha)	0.86	0.61	6.67	84.19	9.14	52.5	6.64	85.55	7.81	60.2	44.95	48.61
Clodinafop-propargyl 15% WP (80 g/ha)	1.38	1.21	8.30	35.42	56.27	54.2	4.90	12.47	82.63	44.9	71.37	72.72
Imazethapyr 10% SL (150 g/ha)	0.89	0.77	7.14	81.12	11.48	39.2	5.35	85.8	8.85	48.6	59.01	58.54
Hand weeding 20 and 45 DAS	1.65	1.25	18.40	55.21	26.38	16.3	8.62	50	41.38	11.6	82.99	90.11
Weedy check (untreated)	-	-	6.91	61.55	31.65	97	5.04	60.80	34.16	117.1	00.0	00.0

Table 5. Effect of different weed management treatments on economics of groundnut

Treatment	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C Ratio	
	2015	2016	2015	2016	2015	2016	2015	2016
Sodium acifluorfen + clodinafop-propargyl (123.75 + 60 g/ha)	27.15	27.50	52.50	62.48	25.35	34.98	1.93	2.27
Sodium acifluorfen + clodinafop-propargyl (165 + 80 g/ha)	27.65	28.00	59.22	71.28	31.57	43.28	2.14	2.55
Sodium acifluorfen + clodinafop-propargyl (206.25 + 80 g/ha)	28.15	28.50	60.48	72.60	32.33	44.10	2.15	2.55
Sodium acifluorfen 20% SL (165 g/ha)	27.15	27.50	36.12	46.20	8.97	18.70	1.33	1.68
Clodinafop-propargyl 15% WP (80 g/ha)	28.15	28.50	43.68	58.96	15.53	30.46	1.55	2.07
Imazethapyr 10% SL (150 g/ha)	26.00	26.40	39.48	51.92	13.48	25.52	1.52	1.97
Hand weeding 20 and 45 DAS	33.25	33.75	62.16	75.68	28.91	41.93	1.87	2.24
Weedy check (untreated)	23.20	23.50	26.04	35.64	2.84	12.14	1.12	1.52

epinasty, hyponasty and necrosis *etc*. were not noticed

Being comparable with hand weeding twice (20 and 45 DAS), post-emergence application of sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC at 206.25 + 100 g/ha be an effective tool for weed management in groundnut.

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Indian Journal of Weed Science **53**(2): 158–163, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Efficacy of sequential application of pre- and early post-emergence herbicides for management of weeds in blackgram

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Article information

DOI: 10.5958/0974-8164.2021.00029.0

Type of article: Research article

Received : 1 January 2021
Revised : 29 April 2021
Accepted : 2 May 2021

Key words
Blackgram
Early post-emergence
Pre-emergence
Nail weeder
Weed management

ABSTRACT

Field experiments were conducted at Tamil Nadu Rice Research Institute, Aduthurai, Thanjavur district, Tamil Nadu, India to evolve efficient and economic weed management practices for irrigated blackgram during *Kharif* (rainy season) 2018 and winter 2018-19. The results revealed that pre-emergence application of pendimethalin1.0 kg/ha on 3 DAS *fb* acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha on 20 DAS effectively reduced weed density and dry matter production. Consequently, higher seed yields of 1.05 and 1.01 t/ha in the *Kharif* and winter seasons were recorded, respectively. The increase was 15.2, 78.7, and 9.2, 86.9% over hand weeding twice, unweeded check in *Kharif* and winter seasons, respectively. Among the treatment combinations, adoption of pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl on 20 DAS had highest gross return (₹ 64,234 and 72,383/ha), net return (₹ 37,374 and 44,722/ha) and B:C (2.39 and 2.62) during *Kharif* and winter seasons, respectively. Hence, this weed management practice could be a viable and cost effective in irrigated blackgram for enhancing production and productivity of blackgram.

INTRODUCTION

Blackgram (*Vigna mungo* L.) is one of the important pulse crops grown in India by contributing about 10% of total pulse production (Anonymous 2018). It can be cultivated in all seasons, but most of the area is under irrigated conditions. India produces about 1.5 to 1.9 million tonnes of blackgram annually from about 3.5 million hectares of area with average productivity of 555 kg/ha (Anonymous 2018). In Tamil Nadu, blackgram is one of the valuable crops among the pulses grown under both irrigated and rainfed situations. Recently, the area under winter blackgram is also increasing in Tamil Nadu due to higher demand in the market. It occupies an area of 0.354 million hectares with a production of 0.259 million tonnes and productivity of 731 kg/ha (Anonymous 2018). Severe competition by weeds especially under high rainfall, high temperature, and high humidity is the major reason for the low productivity. The weeds reduce blackgram yield as high as 66% (Singh *et al.* 2017). Most of the farmers are adopting hand weeding twice which consumes huge labours, time, and is also less economic under high rainfall conditions. Blackgram is very sensitive to weed infestation especially during the first four weeks of its growth period (Randhawa *et al.* 2002). Pre-emergence herbicides control weeds only upto a short period and thereafter late-emerging weeds start competing with crops. Therefore, the best alternative to mitigate crop-weed competition right from the early stages of the crop is either the use of pre-emergence and early post-emergence herbicides alone or in sequence. Keeping the above aspects and constraints in view, this experiment was undertaken to study the efficacy of sequential application of pre- and early post-emergence herbicides in blackgram under irrigated conditions.

MATERIALS AND METHODS

The field experiments were carried out in irrigated blackgram during *Kharif* 2018 and winter season 2018-19 in North Farm (Field No. B2b and F3b) of Tamil Nadu Rice Research Institute, Aduthurai, Thanjavur, Tamil Nadu, India. The experimental site was located in the Cauvery Delta Zone of Tamil Nadu at an altitude of 19.5 m above mean sea level, 11°00' N latitude, and 79° 28' E longitude. This location experiences a tropical humid climate with a hot dry summer from March to June and cool wet winter from September to February. Here North-East monsoon plays a major role in rainfall. The field soil in *Kharif* was sandy loam and neutral in pH (7.4) with low in available N (221 kg/

ha), medium in available P (16 kg/ha) and K (249 kg/ha). While in winter season, the field soil was sandy loam and neutral in pH (7.3) with available N 260 kg/ha, P 21 kg/ha and K 276 kg/ha. The crop (VBN 8) was sown on 12.06.2018 during *Kharif* 2018 and 10.12.2018 during winter 2018-19 using a seed rate of 20 kg/ha and at a row spacing of 30 × 10 cm. Nine treatments consisted of pendimethalin 1.0 kg/ha applied at 3 DAS + hand weeding at 20 DAS, pendimethalin 1.0 kg/ha applied at 3 DAS+ mechanical weeding with nail weeder on 20 DAS, acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha applied as early post emergence(20 DAS), propaquizafop (2.5%) + imazethapyr (3.75% ME) 125g/ha at 20 DAS, pendimethalin 1.0 kg/ha on 3 DAS *fb* acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha at 20 DAS, pendimethalin 1.0 kg/ha on 3 DAS *fb* propaquizafop (2.5%) + imazethapyr (3.75% ME) 125 g/ha at 20 DAS, two mechanical weeding with nail weeder on 15 and 30 DAS, two hand weeding at 15 and 30 DAS, and weedy check in a randomized block design replicated thrice. Knap-sack sprayer fitted with flat-fan nozzle was used for applying herbicides using a spray volume of 500 L/ha. Nail weeder was operated in between crop rows at field capacity by moving in "to and fro" step-wise. Except for weed management practices, rest of all the crop cultivation practices were followed commonly across treatments for proper crop establishment and growth. The square root transformation method $\sqrt{x+0.5}$ was used to normalize the weed data distribution.

RESULTS AND DISCUSSION

Weed flora

The occurrence of weed species in the experimental fields was 29% grasses, 50.5% sedges, and 20.5% broad-leaved weeds (BLW). Grassy weed *Panicum javanicum* (42%) was dominating over other two *i.e*. *Echinochloa colona* (33%) and *Cynodon dactylon* (25%). In sedges, *Cyperus rotundus* (77%) was dominant than *Cyperus difformis* (33%). While among broad-leaved weeds, *Phyllanthus maderaspatensis* (36%) was dominant followed by *Acalypha indica* (14%),*Cleome viscose* (17%), *Eclipta alba* (10%), *Euphorbia geniculate* (4%), *Ipomoea obscura* (5%), *Malvastrum coromandelianum* (6%), and *Physalis minima* (8%).

Weed density

Total weed density was significantly influenced by different weed management practices in both seasons at all stages **(Table 1)**. Among the various weed management practices, hand weeding twice recorded lower weed density of 8.1 and 7.5 no./m^2 at 20 DAS during *Kharif* and winter seasons, respectively. Whereas at 40 and 60 DAS, application of pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl was found to be significantly superior in reducing total weeds to the minimum level of 15.9, 20.8 and 9.5, 13.3 no./m^2 in *Kharif* and winter seasons, respectively. It was on par with pendimethalin *fb* propaquizafop + imazethapyr. Pre-emergence application of pendimethalin on 3 DAS controlled the germination of weeds effectively in the very early stage itself. The effective weed control by pendimethalin during the early crop growth period was further extended upto 60 DAS by sequential application of early post-emergence herbicide acifluorfen-sodium + clodinafop-propargyl or propaquizafop + imazethapyr at 20 DAS. This might be due to suppressing the weeds even up to the later crop growth stages and also due to broad-spectrum weed control during both seasons.

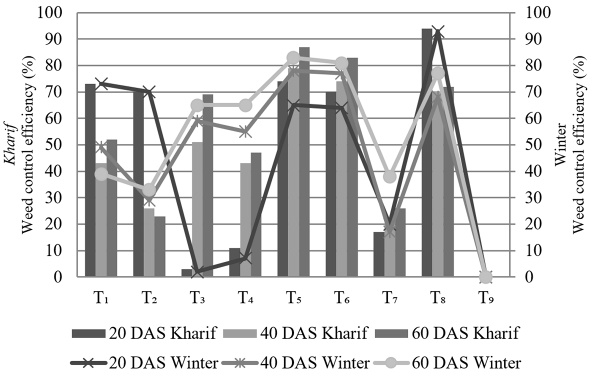
Weed dry matter

Weed management treatments exerted a significant effect on total weed dry matter at all stages in both seasons **(Table 1)**. Irrespective of the weed management practices, total weed dry matter ranged from 18.8 to 322.4 and from 22.5 to 330.7 kg/ha in the *Kharif* and winter season. At 20 DAS, hand weeding twice recorded the lowest total weed dry matter as compared to other treatments in both seasons. At 40 DAS, total weed dry matter ranged from 142.5 to 675.4 and from 113.5 to 845.7 kg/ha in the *Kharif* and winter seasons, respectively. Application of pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl showed lesser total weed dry matter of 142.5 and 113.5 kg/ha in the *Kharif* and winter seasons, respectively. It was closely followed by pendimethalin *fb* propaquizafop + imazethapyr and hand weeding twice. Unweeded control registered significantly higher dry matter production (DMP) at 40 DAS. A similar trend was observed at 60 DAS in both seasons.

The dry matter accumulation of weeds is directly proportional to the yield decline of the crop rather than the weeds population by itself. Prevention of weed germination by pre-emergence application of pendimethalin at 3 DAS was the causal factor for greater reduction in weed dry matter in the early stage of crop growth. The application of pendimethalin showed lesser weed dry matter due to integration of early PoE herbicides acifluorfen-sodium + clodinafop-propargyl and propaquizafop + imazethapyr on 20 DAS at later stages. This result is in accordance with the findings of Panda (2015).

Weed control efficiency

Weed control efficiency (WCE) was higher with pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl at all the growth stages except at 20 DAS in both seasons **(Figure 1)**. At 20 DAS, hand weeding twice at 15 and 30 DAS registered WCE of 94.0 and 93.0% in *Kharif* and winter seasons, respectively. It was closely followed by pendimethalin PE, which registered 65 to 73% WCE in both seasons. Weed control efficiency was higher with pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl at 40 and 60 DAS irrespective of seasons. This might be due longer time and broad spectrum weed control provided by sequential application of these herbicides. Kewat *et al.* (2015) reported similar results on control of monocot and dicot weeds. Minimum WCE was associated with pendimethalin *fb* nail weeder and nail weeder twice at 15 and 30 DAS treatments in both seasons.



T_1- pendimethalin 1.0 kg/ha on 3 DAS + HW on 20 DAS, T_2- pendimethalin 1.0 kg/ha+ nail weeder on 20 DAS, T_3- acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha on 20 DAS, T_4- propaquizafop (2.5%) + imazethapyr (3.75% ME) 125 g/ha on 20 DAS, T_5- pendimethalin 1.0 kg/ha on 3 DAS *fb* acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha on 20 DAS, T_6- pendimethalin 1.0 kg/ha on 3 DAS *fb* propaquizafop (2.5%) + imazethapyr (3.75% ME) 125 g/ha on 20 DAS, T_7- two nail weeder on 15 and 30 DAS, T_8- two hand weeding on 15 and 30 DAS, T_9- weedy check.

Figure 1. Effect of weed management practices on weed control efficiency in irrigated blackgram

Growth attributes

The weed management practices were significantly influenced in DMP at 40 and 60 DAS except at 20 DAS in both seasons **(Table 2)**. At 20 DAS, higher crop dry matter production of 578 and 556 kg/ha was obtained with nail weeder during the *Kharif* season and pendimethalin *fb* propaquizafop + imazethapyr treatments during winter season. At 40 DAS, application of pendimethalin followed by acifluorfen-sodium + clodinafop-propargyl showed distinct variation in dry matter of 3.28 and 3.11 t/ha in *Kharif* and winter seasons, respectively. At 60 DAS, pendimethalin followed by acifluorfen-sodium + clodinafop-propargyl was significantly superior and recorded the highest DMP of 3.89 t/ha and 3.76 t/ha in *Kharif* and winter seasons, respectively. This was at par with pendimethalin *fb* propaquizafop + imazethapyr and hand weeding twice (3.70 t/ha). Unweeded check registered lower dry matter at all stages in both seasons.

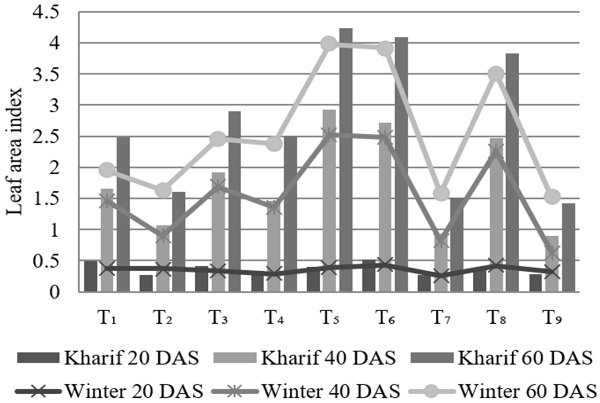
Leaf area index was greater with herbicide applied plots over the unweeded check and two nail weeder at 15 and 30 DAS irrespective of stages and seasons **(Figure 2)**. At 40 DAS, pendimethalin followed by acifluorfen-sodium + clodinafop-propargyl was significantly superior and recorded

Table 1. Effect of weed management practices on density and dry weight of weed in irrigated blackgram

Treatment	Weed density (no./m^2)						Weed dry matter production (kg/ha)					
	20 DAS		40 DAS		60 DAS		20 DAS		40 DAS		60 DAS	
	Kharif	winter	*Kharif*	winter	*Kharif*	winter	*Kharif*	winter	*Kharif*	winter	*Kharif*	winter
Pendimethalin 3 DAS *fb* hand weeding 20 DAS	4.94 (24.8)	5.18 (27.2)	7.55 (57.1)	6.41 (41.3)	5.91 (34.9)	6.68 (44.6)	9.32 (86.9)	9.43 (88.9)	19.67 (387.6)	18.28 (334.9)	20.10 (406.6)	21.63 (468.6)
Pendimethalin 3 DAS *fb* Nail weeder 20 DAS	5.58 (31.1)	5.69 (32.7)	8.43 (71.5)	7.38 (55.5)	7.70 (59.2)	7.46 (55.8)	9.81 (96.5)	9.86 (98.2)	22.19 (496.5)	21.45 (465.5)	25.50 (650.2)	22.53 (508.2)
Acifluorfen-sodium + clodinafop-propargyl 20 DAS	9.31 (87.0)	8.57 (74.4)	6.94 (48.2)	5.98 (36.2)	5.66 (32.1)	5.63 (32.3)	17.68 (313.7)	17.96 (324.1)	18.17 (330.7)	16.32 (266.4)	16.29 (265.7)	16.23 (264.7)
Propaquizafop + imazethapyr 20 DAS	8.14 (66.8)	8.36 (70.9)	7.10 (50.8)	6.67 (45.3)	7.84 (61.6)	5.57 (31.6)	16.77 (286.6)	17.42 (307.2)	19.54 (384.6)	17.10 (293.9)	20.98 (444.6)	16.39 (268.6)
Pendimethalin 3 DAS *fb* acifluorfen-sodium + clodinafop-propargyl 20 DAS	4.93 (24.4)	5.45 (30.2)	3.91 (15.9)	4.51 (20.8)	3.07 (9.5)	3.89 (13.3)	9.22 (85.2)	10.65 (114.7)	11.72 (142.5)	12.01 (145.5)	10.53 (113.5)	11.18 (127.2)
Pendimethalin 3 DAS *fb* propaquizafop + imazethapyr 20 DAS	5.27 (28.0)	5.36 (28.7)	4.33 (19.2)	4.89 (24.1)	3.69 (13.7)	3.89 (15.2)	9.76 (96.4)	10.87 (118.5)	13.14 (173.4)	12.07 (150.1)	11.86 (142.10	12.06 (145.4)
Two NW 15 and 30 DAS	8.58 (74.3)	7.68 (59.3)	8.89 (79.9)	8.39 (70.9)	7.89 (62.3)	7.02 (49.6)	16.27 (266.6)	16.23 (264.6)	23.22 (540.9)	23.21 (540.3)	24.98 (624.3)	21.63 (472.3)
Two HW 15 and 30 DAS	2.84 (8.1)	2.74 (7.5)	5.42 (30.0)	4.82 (23.5)	4.12 (16.8)	3.91 (15.5)	4.31 (18.8)	4.69 (22.5)	14.04 (199.8)	14.46 (209.8)	15.36 (236.2)	13.24 (176.2)
Weedy check	9.31 (86.8)	8.72 (76.1)	9.21 (85.3)	8.68 (75.4)	9.71 (94.7)	9.13 (83.5)	17.95 (322.4)	18.18 (330.7)	25.93 (675.4)	25.54 (652.4)	29.07 (845.70	27.57 (762.4)
LSD (p=0.05)	1.07	1.17	1.39	1.33	0.68	1.15	2.34	1.75	3.13	2.70	2.70	2.51

Figures in parentheses are original values; Data subjected to square root transformation higher LAI of 2.93 and 2.52 during the *Kharif* and winter seasons, respectively.

The crop growth rate accelerated steadily upto 40 DAS and then turned to decline from 40 DAS to 60 DAS **(Table 2)**. During the early stages of the crop (20-40 DAS), significantly higher CGR was obtained with pendimethalin followed by acifluorfen-sodium + clodinafop-propargyl and it was comparable with pendimethalin *fb* propaquizafop + imazethapyr and hand weeding twice in both seasons. Whereas at later stages of the crop (40-60 DAS), though higher values of CGR was recorded with pendimethalin followed by acifluorfen-sodium + clodinafop-propargyl, it was at par with the pre-emergence applied pendimethalin alone or integrated with one hand weeding. The growth attributes of irrigated blackgram, *viz.* LAI, DMP, CGR were greater with the application of pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl due to effective suppression of emerging weeds especially grasses and broad-leaved weeds at the early as well as later stages of the crop growth period. Next in order, pendimethalin *fb* propaquizafop + imazethapyr also improved growth characters and it was statistically in line with hand weeding twice. This was supported by Marimuthu *et al.* (2016) who reported that sequential application of early and post-emergence herbicides is far better in weed control than two hand weeding in blackgram.



T_1- pendimethalin 1.0 kg/ha on 3 DAS + hand weeding on 20 DAS, T_2- pendimethalin 1.0 kg/ha+ nail weeder on 20 DAS, T_3- acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha on 20 DAS, T_4- propaquizafop (2.5%) + imazethapyr (3.75% ME) 125 g/ha on 20 DAS, T_5- pendimethalin 1.0 kg/ha on 3 DAS *fb* acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha on 20 DAS, T_6- pendimethalin 1.0 kg/ha on 3 DAS *fb* propaquizafop (2.5%) + imazethapyr (3.75% ME) 125g/ha on 20 DAS, T_7- two nail weeder on 15 and 30 DAS, T_8- two hand weeding on 15 and 30 DAS, T_9- weedy check.

Figure 2. Influence of weed management practices on LAI in irrigated blackgram

Table 2. Effect of weed management practices on growth attributes in irrigated blackgram

Treatment	Dry matter production (t/ha)						CGR (kg/ha/day)			
	20 DAS		40 DAS		60 DAS		20 - 40 DAS		40 - 60 DAS	
	Kharif	Winter	*Kharif*	Winter	*Kharif*	Winter	*Kharif*	Winter	*Kharif*	Winter
Pendimethalin 3 DAS *fb* hand weeding 20 DAS	0.47	0.49	2.58	2.16	2.97	2.65	106	83	19	25
Pendimethalin 3 DAS *fb* Nail weeder 20 DAS	0.37	0.42	2.22	2.07	2.57	2.43	93	82	17	18
Acifluorfen-sodium + clodinafop-propargyl 20 DAS	0.41	0.48	2.62	2.53	3.09	2.78	111	103	23	12
Propaquizafop + imazethapyr 20 DAS	0.32	0.50	2.47	2.34	2.67	2.70	107	92	10	18
Pendimethalin 3 DAS *fb* acifluorfen-sodium + clodinafop-propargyl 20 DAS	0.44	0.51	3.28	3.11	3.89	3.76	142	130	31	32
Pendimethalin 3 DAS *fb* propaquizafop + imazethapyr 20 DAS	0.43	0.56	2.89	3.07	3.51	3.70	123	126	31	32
Two NW 15 and 30 DAS	0.58	0.48	2.12	2.19	2.40	2.42	77	86	14	12
Two HW 15 and 30 DAS	0.53	0.49	2.79	2.73	3.38	3.39	113	112	29	33
Weedy check	0.46	0.53	2.06	2.10	2.36	2.34	80	78	15	12
LSD (p=0.05)	NS	NS	0.45	0.42	0.45	0.45	27.31	24.29	14	16

Table 3. Effect of weed management practices on yield attributes and grain yield in irrigated blackgram

Treatment	Clusters/plant		Pods/plant		Seeds/pod		100 seed weight (g)		Grain yield (kg/ha)	
	Kharif	Winter	*Kharif*	Winter	*Kharif*	Winter	*Kharif*	Winter	*Kharif*	Winter
Pendimethalin 3 DAS *fb* hand weeding 20 DAS	9.1	8.3	30.7	26.2	6.8	6.0	4.8	4.5	826	719
Pendimethalin 3 DAS *fb* Nail weeder 20 DAS	7.8	7.1	25.3	23.7	6.5	6.6	4.5	4.3	694	603
Acifluorfen-sodium + clodinafop-propargyl 20 DAS	9.7	9.4	33.5	30.8	7.2	6.7	4.6	4.9	887	815
Propaquizafop + imazethapyr 20 DAS	8.8	9.1	29.0	30.5	6.9	6.3	4.8	4.0	745	788
Pendimethalin 3 DAS *fb* acifluorfen-sodium + clodinafop-propargyl 20 DAS	12.5	11.0	44.4	41.3	7.5	6.9	4.6	4.3	1053	1019
Pendimethalin 3 DAS *fb* propaquizafop + imazethapyr 20 DAS	11.2	10.5	38.8	40.9	7.3	7.1	4.4	4.5	968	983
Two Nail weeder 15 and 30 DAS	7.1	7.0	22.4	23.0	6.1	6.3	4.7	4.1	627	571
Two hand weeding 15 and 30 DAS	10.6	10.1	36.3	36.0	7.5	6.6	4.9	4.7	914	933
Weedy check	6.4	7.0	20.9	21.3	6.2	6.4	4.6	4.3	589	545
LSD (p=0.05)	2.31	2.06	3.97	3.75	0.43	0.55	NS	NS	155	129

Yield attributes

All the yield attributes were significantly influenced by different weed management practices in both seasons **(Table 3)**. Pendimethalin 1.0 kg/ha at 3 DAS *fb* acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha at 20 DAS showed improvement in yield attributes, *viz*. clusters/plant (95.3 and 57.1%), pods/plant (112.4 and 93.8%), seeds/pod (20.9 and7.81%) over unweeded check during *Kharif* and winter seasons, respectively. While unweeded check registered lower attributes as compared to all weed control treatments.

Higher leaf area, biomass and total branches production gained through effective and prolonged weed control by these promising treatments throughout the crop season might have supported the crop in the conversion of more branches and biomass into a productive one. This is in agreement with the findings of Patel *et al.* (2018). Whereas, unweeded control due to the severe weed competition exerted by weeds for the available resources throughout the crop growth period might have lowered pods/plant and seeds/pod. Similar results were observed in blackgram by Gupta *et al.* (2014).

Yield

Pre-emergence application of pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl enhanced the production potential of irrigated blackgram as evident from higher seed yield of 1053 and 1019 kg/ha with the increased yield of 78.7and 86.9% over unweeded control in *Kharif* and winter season, respectively **(Table 3)**. This could be mainly because of an excellent suppression of all weeds right from crop emergence to harvest. This created a congenial environment similar weed free situation for irrigated blackgram and improved the crop growth in terms of biomass and thus recorded superior yield attributes. This in turn was clearly reflected on the yield potential of the irrigated blackgram. Nail weeder adopted plots produced lesser seed yield than hand weeding twice treatment. It might be due to insufficient intra-row weed removal. On the other hand, weedy check with more weed density right from sowing to crop maturity, subjected crop to more stress for utilizing essential resources and therefore, resulted in inferior yield traits and lower yields.

Nutrient removal by weeds

The extent of weed competition with irrigated blackgram was also assessed through the removal of nutrients under unweeded conditions, where there was higher uptake of nitrogen by weeds varying from 14.1 to 13.13 kg/ha in both seasons **(Table 4)**. Pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl treatment curtailed the nitrogen (85 and 83%), phosphorous (86 and 83%), potassium (85 and 85%) uptake in *Kharif* and

Table 4. Effect of weed management practices on nutrient removal (kg/ha) at 60 DAS

Treatment	Weeds						Crop					
	Nitrogen		Phosphorous		Potassium		Nitrogen		Phosphorous		Potassium	
	Kharif	Winter	*Kharif*	Winter	*Kharif*	Winter	*Kharif*	Winter	*Kharif*	Winter	*Kharif*	Winter
Pendimethalin 3 DAS *fb* hand weeding 20 DAS	7.07	8.14	1.16	1.26	6.47	7.73	49.9	45.6	6.36	5.50	50.6	45.4
Pendimethalin 3 DAS *fb* Nail weeder 20 DAS	11.43	8.87	1.74	1.38	10.34	8.47	40.4	37.0	5.45	4.70	43.8	39.0
Acifluorfen-sodium + clodinafop-propargyl 20 DAS	4.67	4.40	0.71	0.68	4.32	3.83	56.3	52.3	7.37	7.16	54.8	51.9
Propaquizafop + imazethapyr 20 DAS	7.93	4.97	1.19	0.74	7.13	4.33	42.8	48.1	6.03	6.70	46.3	50.1
Pendimethalin 3 DAS *fb* acifluorfen-sodium + clodinafop-propargyl 20 DAS	2.13	2.29	0.32	0.34	1.80	1.88	73.4	68.6	8.77	9.17	66.5	66.4
Pendimethalin 3 DAS *fb* propaquizafop + imazethapyr 20 DAS	3.13	2.50	0.46	0.39	2.67	2.23	67.2	68.5	8.12	8.77	60.1	63.3
Two Nail weeder 15 and 30 DAS	10.67	8.10	1.69	1.29	9.83	8.30	36.4	36.0	4.97	4.57	39.1	37.7
Two hand weeding 15 and 30 DAS	4.29	3.11	0.66	0.47	3.90	2.70	60.4	59.8	7.65	7.90	57.6	58.3
Weedy check	14.10	13.13	2.25	2.06	12.77	12.67	34.7	34.8	4.62	4.54	36.1	36.0
LSD (p=0.05)	1.88	1.92	0.71	0.70	2.11	2.08	8.68	10.21	1.49	0.70	9.07	8.82

Table 5. Influence of weed management practices on economics in irrigated blackgram

Treatment	Cost of cultivation (x10^3 ₹/ha)		Gross income (x10^3 ₹/ha)		Net income (x10^3 ₹/ha)		B:C ratio	
	Kharif	Winter	*Kharif*	Winter	*Kharif*	Winter	*Kharif*	Winter
Pendimethalin 3 DAS *fb* hand weeding 20 DAS	28.05	29.07	50.40	51.12	22.35	22.05	1.80	1.76
Pendimethalin 3 DAS *fb* Nail weeder 20 DAS	26.61	27.53	42.41	42.91	15.79	15.38	1.59	1.56
Acifluorfen-sodium + clodinafop-propargyl 20 DAS	26.03	26.81	54.09	57.91	28.06	31.10	2.08	2.16
Propaquizafop + imazethapyr 20 DAS	28.21	28.99	45.45	55.93	17.25	26.94	1.61	1.93
Pendimethalin 3 DAS *fb* acifluorfen-sodium + clodinafop-propargyl 20 DAS	26.86	27.66	64.23	72.38	37.37	44.72	2.39	2.62
Pendimethalin 3 DAS *fb* propaquizafop + imazethapyr 20 DAS	29.03	29.83	59.03	69.84	29.99	40.01	2.03	2.34
Two Nail weeder 15 and 30 DAS	27.80	28.84	38.32	40.61	10.52	11.77	1.38	1.41
Two hand weeding 15 and 30 DAS	30.68	31.92	55.76	66.24	25.08	34.32	1.82	2.08
Weedy check	23.77	24.53	35.98	38.81	12.21	14.28	1.51	1.58

winter seasons, respectively. While weedy check resulted into higher uptake of NPK throughout the crop period. Lower removal of nutrients by weeds under pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl, pendimethalin *fb* propaquizafop + imazethapyr and even hand weeding twice was due to lesser weed population and dry matter even at a later stage. Similar reports were expressed by Komal *et al.* (2015) that nutrient uptake by weeds was less in green gram with herbicide applied treatments than any other treatments.

Nutrient uptake by crop

In general, the blackgram crop utilized more of N and K than P in both seasons. In *Kharif* and winter season, application of pendimethalin followed by acifluorfen-sodium + clodinafop-propargyl was found to be superior with an increased uptake of nitrogen (112 and 97%), phosphorous (90 and 101%) and potassium (84 and 84.4%) as well over the weedy check **(Table 4)**. All the weed control practices showed higher uptake of nutrients by blackgram than the unweeded check. This finding is in close confirmity with the results reported by Poornima *et al.* (2018). Among distinct weed control measures, pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl accumulated higher nutrients than the other treatments in blackgram. This is due to effective weed control especially grasses and broad-leaved weeds during the critical stage of the crop.

Economics

The cost of cultivation varied greatly among the different weed management practices under irrigated blackgram **(Table 5)**. Pre-emergence application of pendimethalin *fb* acifluorfen-sodium + clodinafop propargyl fetched higher gross returns (₹ 64,234 and 72,383/ha) and net returns (₹ 37,374 and 44,722/ha) in *Kharif* and winter respectively. It was *fb* PE of pendimethalin *fb* propaquizafop + imazethapyr. The higher returns are mainly due to lower cost of cultivation especially for the labour wages engaged in spraying. In terms of B:C ratio, PE of pendimethalin *fb* acifluorfen-sodium + clodinafop-propargyl on 20 DAS recorded higher B:C values of 2.39 and 2.62 in *Kharif* and winter season respectively. Similarly, Shruthi and Salakinkop (2015) reported that higher net returns and B:C was fetched with sequential application of PE and PoE herbicides over hand weeding.

Conclusion

Based on the present investigation, PE of pendimethalin 1.0 kg/ha at 3 DAS *fb* acifluorfen-sodium (16.5%) + clodinafop-propargyl (8% EC) 187.5 g/ha at 20 DAS and pendimethalin 1.0 kg/ha at 3 DAS *fb* propaquizafop (2.5%) + imazethapyr (3.75% ME) 125 g/ha at 20 DAS were most effective treatments to control weeds effectively and attain higher yield and higher income in irrigated blackgram.

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Indian Journal of Weed Science **53**(2): 164–168, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of conservation agriculture practices on weed management in okra under rice- okra-green manure cropping system

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Article information

DOI: 10.5958/0974-8164.2021.00030.7

Type of article: Research article

Received : 7 February 2021

Revised : 29 May 2021

Accepted : 2 June 2021

Key words

Brown manuring

Crop residue mulch

Flat bed

Green manuring

Raised bed

Rice-okra cropping system

ABSTRACT

A field experiment was carried out at Agronomy Farm, College of Agriculture, Vellanikkara in, Kerala, India a randomized block design consisted of ten treatments having three replicates during the years 2019 to 2021 to develop a conservation agricultural practices for upland rice-vegetable-green manure cropping system. It has been found that different conservation treatments had a significant effect on weed density, weed dry matter production, weed control efficiency, yield and economics in okra (lady finger). The results revealed that the lowest density and dry matter of weeds were recorded in direct-seeded rice in flat bed + green manuring followed by okra with crop residue mulch at 30,60,90 DAS and at harvest. Highest weed control efficiency (59-67%) and yield (16.47 t/ha) in okra was registered in direct-seeded rice in flat bed + green manuring followed by okra with crop residue mulch. The highest weed density and weed dry matter production was noticed in direct-seeded rice in flat bed-okra. While considering the whole cropping system the highest B:C was found in direct-seeded rice in flat bed + green manuring followed by okra-green manure based cropping system (3.31).

INTRODUCTION

Rice is major crop in Kerala and it grows both as transplanted wetland rice and also upland rice. Weeds are the main constraints in upland rice. Chemical herbicides are generally used for weed control but the excessive use of herbicides causes ecological imbalance (Liu *et al.*,2015). In this situation, conservation agriculture practices are gaining importance for environmental sustainability. Conservation agriculture (CA) is an approach to manage agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base, and which emphasize minimum soil disturbance, permanent soil cover and diversified crop rotation. CA techniques like green manuring, mulching *etc*. can effectively control the weeds (Navas *et al.* 2017). Yadav *et al.* (2018) reported that among two types of tillage in rice field, conventional tillage with 100% residue incorporation registered higher total weed density of 89-168 weeds/m^2 and weed biomass of 9.6–183 g/m^2 on dry weight basis over no-tillage with 100% residue retention which recorded 75-161 weed/m^2 and 8-155 g/m^2 on dry weight basis. So minimum soil disturbance can reduce the weed population. Crop diversification reduces the weeds than monocropping so a rice - vegetable based cropping systems helps the farmers to diverse the weed population. But the impact studies on conservation agriculture-based resource conserving techniques on weed management in the said cropping systems are lacking. So the study is proposed with an objective for developing cost effective, eco-friendly resource conservation technologies for upland rice based cropping system. Therefore, in the present study the effect of conservation agriculture practices on weed management in okra (lady finger) in rice-okra-green manure cropping system was carried out.

MATERIALS AND METHODS

The field experiment was conducted at Agronomy Farm, College of Agriculture, Vellanikkara, Kerala, India (10°31' N latitude and 76°13' E) from May, 2019 to March, 2021. The soil of the experimental site was sandy loam with pH4.91, EC0.71dS/m, OC (1.22%), available N (144.4 kg/ha), available P (23.29 kg/ha) and available K (291.36 kg/ ha). Rice crop was raised during May as first crop followed by okra in September as second crop and cowpea was raised in January as the third crop for green manuring with ten treatments and each replicated thrice in a randomised block design.Crops were raised in flat bed (5 x 4 m) and in raised beds *i.e.* 3 raised beds (5m x 1m x 30 cm) adjusted in the area of 5 x 4 m. Treatments consists of direct-seeded rice (DSR) in flat bed + brown manuring (BM)-okra + green manuring (GM), DSR in flat bed + BM-okra + crop residue mulch, DSR info at bed + GM-okra +GM, DSR in flat bed + GM-okra + crop residue mulch, DSR in raised bed + BM-okra + GM, DSR in raised bed + BM-okra + crop residue mulch, DSR in raised bed + GM -okra + GM, DSR in raised bed + GM-okra + crop residue mulch, DSR in flat bed-okra, DSR in raised bed-okra.

Okra variety '*Arka Anamika*' was used for this study. The previous crop rice was a direct-seeded one. Initially the field was ploughed at the start of experiment and sowing of rice was done manually. In second year minimum land preparation was done for rice crop. Crop residue which is left in the above ground portion after harvest of rice was cleaned by using brush cutter. Brown manuring in rice was done at 25 DAS by applying 2,4-D 1.25 kg/ha. Field was made weed free before sowing with minimum soil disturbance using brush cutter after harvest of rice. After rice harvest, the okra seeds at the rate of 8.5 kg/ha was dibbled in planting holes at a spacing of 60 x 30 cm without disturbing the rest of the area and earthing up was given at the time of fertilizer application with minimum disturbance by piling soil up just as a support around base of the plant. Fertilizers were applied as urea, phosphate and potash at the rate of 55:35:70 N, P and K kg/ha at the time of sowing. Another 55 kg N/ha was applied one month after sowing.

Cowpea seeds were also dibbled in alternate rows along with okra for in situ green manuring for only the treatments where green manuring is specified. The cowpea was uprooted and spread as mulch at 25 DAS in those treatments (1-1.5 t/ha). For crop residue mulching, 50% straw of previous rice crop (5-6 t/ha) was retained at the time of harvest and it was cut and spread in the field using brush cutter for crop residue mulching before planting of okra. After harvest of okra, the field was cleaned by brush cutter and cowpea seeds was sown as sole green manure crop. Cowpea was grown in between rows of okra only in the treatments were the insitu green manuring was specified as mentioned above it was cut and spreaded as mulch in those treatments at 25 DAS. After harvest of okra the field was cleaned by brush cutter and cowpea seeds were sowed as green manure as third crop in sequence of this cropping system. A quadrat of 1 m^2 was used and different weed species present within the quadrat were collected. Weeds were categorized into grasses, broad-leaf weeds and sedges and counted separately. Weeds collected were oven dried at 70 °C to attain constant dry weight. Data were tabulated and subjected to statistical analysis 'WASP 2' (Statistical package, ICAR Goa) and the significance among the treatments was estimated at 5 per cent of probability and pooling was done for two years data and the data on weed density was subjected to square root transformation before analysis.

RESULTS AND DISCUSSION

Weed flora

Weed flora of the experimental field consisted of grasses, broad-leaf weeds (BLW) and sedges. Among grassy weeds in okra *Setaria* spp., *Digitaria sanguinalis, Panicum maximum, Oryza sativa* and *Brachiaria* spp. were dominant. The broad-leaf weeds identified were *Alternanthera bettzickiana, Ageratum conyzoides, Euphorbia hirta, Euphorbia geniculata, Mollugo disticha, Mitracarpus hirtus, Ludwigia perennis, Hemidesmus indicus Phyllanthus niruri, Lindernia crustacean, Commelina benghalensis* and *Trianthema portulacastrum*. *Cyperus iria* was the only sedge identified in the field.

Weed density

The conservation treatments had a significant effect on weed density in okra (lady finger) (was sown during both the years of study at 30, 60 DAS and at harvest (**Table 1**). Minimum grasses, broad-leaf weeds and sedges density after 30 days (7.19,5.91, 1.28 no./m^2), 60 days (4.22, 6.47, 1.21 no./m^2) and harvest (3.24, 4.62, 1.00 no./m^2) was observed in direct-seeded rice in flat bed + green manuring-okra + crop residue mulching. Residual effect of previous crop might have influenced the weed population of subsequent crop. Rotation with green manure crop in a cropping system reduces the soil weed seed bank and it can mitigate the weed problems in succeeding crops (Melander *et al.* 2020). The highest weed density was recorded in direct-seeded rice in flat bed –okra where no conservation practice was followed. Crop mulching practice in okra caused more weed reduction compared to insitu green manuring. This might be due to the covering of soil surface right from the planting onwards and hence preventing/restricting the emergence of weeds. Similar findings were reported by Rehmann 2017 that crop rotation helps for breaking the life-cycle of weeds than mono cropping and the soil cover (mulches) inhibit the weed seed germination by preventing the sunlight or by the exudation of allelopathic substances.

Table 1. Effect of treatments on weed density (no./m²) at 30 , 60 DAS and at harvest of okra (pooled data 2 years)

Treatment	Grasses*			Broad-leaf weeds*			Sedges*		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest
Direct-seeded rice in flat bed + brown manuring - okra+ green manuring	10.16 (103.3)	5.75 (33.2)	4.86 (23.7)	7.59 (58.0)	8.07 (65.2)	6.65 (44.2)	3.11 (9.7)	2.67 (7.2)	1.87 (3.5)
Direct-seeded rice in flat bed + brown manuring - okra + crop residue mulch	8.33 (69.5)	4.81 (23.2)	4.14 (17.2)	6.82 (46.5)	7.29 (53.2)	5.64 (31.8)	1.92 (3.8)	1.79 (3.3)	1.41 (2.0)
Direct-seeded rice in flat bed + green manuring - okra + green manuring	9.85 (97.2)	5.40 (29.2)	4.58 (21.0)	6.93 (48.0)	8.17 (66.7)	6.78 (46.0)	2.76 (7.7)	2.37 (5.7)	1.72 (3.00
Direct-seeded rice in flat bed + green manuring - okra + crop residue mulch	7.19 (52.3)	4.22 (17.8)	3.24 (10.5)	5.91 (35.0)	6.47 (41.8)	4.62 (21.3)	1.28 (1.7)	1.21 (1.5)	1.00 (1.0)
Direct-seeded rice in raised bed + brown manuring - okra + green manuring	10.86 (118.3)	6.35 (40.3)	5.60 (31.3)	9.83 (96.8)	9.91 (98.3)	8.92 (79.8)	3.29 (10.8)	3.37 (11.3)	2.19 (4.8)
Direct-seeded rice in raised bed + brown manuring -okra+ crop residue mulch	11.18 (125.2)	6.47 (41.8)	5.43 (29.5)	10.13 (102.8)	9.96 (99.3)	8.94 (80.2)	3.31 (11.0)	3.00 (9.0)	2.44 (6.0)
Direct-seeded rice in raised bed + green manuring - okra + green manuring	10.93 (119.5)	6.23 (38.8)	5.20 (27.0)	11.35 (128.8)	9.15 (84.0)	7.99 (64.2)	3.78 (14.3)	2.83 (8.0)	2.88 (8.3)
Direct-seeded rice in raised bed + green manuring - okra+ crop residue mulch	10.05 (101.0)	5.87 (34.5)	5.10 (26.0)	8.02 (64.3)	8.40 (70.5)	7.23 (52.3)	3.21 (10.3)	2.76 (7.7)	1.76 (3.2)
Direct-seeded rice in flat bed – okra	15.82 (250.3)	8.28 (68.7)	7.10 (50.5)	15.55 (242.0)	11.36 (129.2)	10.49 (110.0)	4.58 (21.0)	4.62 (21.3)	4.20 (17.7)
Direct-seeded rice in raised bed – okra	13.14 (172.8)	6.98 (48.7)	6.10 (37.3)	13.38 (179.0)	10.65 (113.3)	9.62 (92.7)	4.40 (19.3)	4.24 (18.0)	3.34 (11.2)
LSD (p=0.05)	0.83	0.44	0.40	0.83	0.61	0.71	0.44	0.41	0.37

*$\sqrt{x+0.5}$ transformed values, original values in parentheses

Total weed count and weed dry matter production

The conservation treatments significantly influenced in total weed density and weed dry matter production (**Table 2**). Among all treatments, direct-seeded rice in flat bed-green manuring-okra + crop residue mulching recorded lowest total weed density (9.41, 7.82, 5.73 no/m^2) and weed dry matter production (22.75, 23.58, 17.50 g/m^2) at 30,60 DAS and at harvest respectively. The low weed density might be the reason for lowering the dry matter production of weeds. The result of the present study was in consonance with the findings of Sharma and Sharma, (2019) who also reported the less weed density in mulched plot and which was responsible for reduction of weed dry matter production. The highest weed density and weed dry matter production was reported in direct-seeded rice in flat bed–okra without conservation practices. The less weed density and dry matter production were reported in crops inter-cropped with green manure due to less competition of weeds to nutrients, space, water and light in early stage (Barla *et al*. 2016). Minimum tillage and crop cover might have helped in reducing weed seed germination and thereby reduction in weed infestation in treatments with conservation agriculture practices than without conservation practices.

Weed control efficiency

Among all the conservation treatments, direct-seeded rice in flat bed + green manuring - okra + crop residue mulch showed maximum weed control efficiency of 60-67% compared to all other treatments (**Table 2**). High weed control efficiency under this might be due to their mulching property which suppressed the weed growth. This result was also in accordance with the findings of Baghel *et al.* (2018) that who reported higher weed control efficiency where conservation principles for rice-based cropping system were followed.

Yield and yield attributes

The number of fruit plant (21.50), length of fruit (18.48 cm), yield plant (138.95 g) and a total yield of 16.49 t/ha was recorded in direct-seeded rice in flat bed – okra + crop residue mulching (**Table 3**). The lowest weed population might be the reason for improving the yield. Das *et al.* (2019) assessed the effect of conservation tillage and four rice residue management practices on lentil in India, and reported that lentil can be cultivated after rice by retaining the stubbles of rice which has a significant difference in yield than other treatments. The lowest yield of 7.71 t/ha was registered in direct-seeded rice in raised bed + brown manuring – okra + green manuring. Due to

Table 2. Effect of treatments on total weed density (no./m2) and weed dry matter production (g/m²) and weed control efficiency (WCE) of okra (pooled data 2 years)

Treatment	30 DAS		60 DAS*		Harvest*		WCE 30 DAS	WCE 60 DAS	WCE Harvest
	*Total weed density	Weed dry matter production	*Total weed density	Weed dry matter production	*Total weed density	Weed dry matter production			
Direct-seeded rice in flat bed + brown manuring - okra+ green manuring	13.08 (171.0)	37.83	10.27 (105.5)	34.50	8.45 (71.3)	23.67	45.64	41.46	52.12
Direct-seeded rice in flat bed + brown manuring - okra + crop residue mulch	10.94 (119.8)	28.85	8.92 (79.7)	29.42	7.14 (51.0)	22.21	58.63	49.99	55.010
Direct-seeded rice in flat bed + green manuring - okra + green manuring	12.36 (152.8)	34.87	10.08 (101.5)	33.25	8.37 (70.0)	25.00	49.97	43.57	49.49[c]
Direct-seeded rice in flat bed + green manuring - okra + crop residue mulch	9.41 (89.0)	22.75	7.82 (61.2)	23.58	5.73 (32.8)	17.50	67.26	59.8	64.58
Direct-seeded rice in raised bed + brown manuring - okra + green manuring	15.02 (226.0)	44.96	12.24 (150.0)	43.50	10.76 (116.0)	35.75	35.28	26.04	27.62
Direct-seeded rice in raised bed + brown manuring -okra+ crop residue mulch	15.45 (239.0)	46.69	12.24 (150.2)	37.83	10.74 (115.7)	28.50	32.87	35.57	42.18
Direct-seeded rice in raised bed + green manuring - okra + green manuring	16.21 (262.7)	45.58	11.43 (130.8)	38.42	9.97 (99.5)	31.25	34.37	34.80	36.67
Direct-seeded rice in raised bed + green manuring - okra+ crop residue mulch	13.25 (175.7)	39.92	10.61 (112.7)	35.17	9.03 (81.5)	26.58	42.77	40.40	46.08
Direct-seeded rice in flat bed – okra	22.65 (513.3)	69.83	14.80 (219.2)	58.92	13.35 (178.2)	49.42	0.00	0.00	0.00
Direct-seeded rice in raised bed – okra	19.26 (371.2)	55.26	13.42 (180.0)	52.08	11.88 (141.2)	41.92	20.58	11.55	15.12
LSD (p=0.05)	0.97	6.74	0.60	4.68	0.64	6.50	6.77	7.80	6.77

*$\sqrt{x+0.5}$ transformed values, original values in parentheses

Table 3. Effect of treatments on yield, yield attributes and economics of okra (pooled data 2 years)

Treatment	No. of fruits / plant	Length of the fruit (cm)	Yield g/ plant)	Yield First year (t/ha)	Yield second year (t/ha)	Yield pooled (t/ha)	Cost of cultivation ($x10^3$ `/ha)	Gross return ($x10^3$ `/ha)	Net return ($x10^3$ `/ha)	B:C ratio
Direct-seeded rice in flat bed + brown manuring - okra+ green manuring	18.57	15.68	262.1	14.73	14.35	14.55	160.30	510.10	349.79	3.17
Direct-seeded rice in flat bed + brown manuring - okra + crop residue mulch	20.87	17.18	286.7	15.98	15.84	15.91	159.63	557.22	397.59	3.47
Direct-seeded rice in flat bed + green manuring - okra + green manuring	19.22	16.93	270.2	14.99	15.00	14.99	160.30	524.75	364.45	3.26
Direct-seeded rice in flat bed + green manuring - okra + crop residue mulch	21.50	18.48	296.8	16.24	16.70	16.47	159.85	575.44	415.58	3.59
Direct-seeded rice in raised bed + brown manuring - okra + green manuring	12.25	13.33	138.9	76.77	7.75	7.71	152.38	269.74	117.35	1.76
Direct-seeded rice in raised bed + brown manuring -okra+ crop residue mulch	15.50	14.07	183.0	10.05	10.27	10.15	150.38	354.89	204.51	2.35
Direct-seeded rice in raised bed + green manuring - okra + green manuring	14.88	15.03	160.3	8.45	9.34	8.90	150.38	309.25	158.87	2.05
Direct-seeded rice in raised bed + green manuring - okra+ crop residue mulch	16.83	15.15	203.9	11.56	11.07	11.31	152.98	397.28	244.29	2.58
Direct-seeded rice in flat bed – okra	19.08	15.63	254.2	14.26	13.94	14.11	183.63	494.50	310.87	2.68
Direct-seeded rice in raised bed – okra	16.17	14.07	195.7	10.80	10.91	10.86	157.88	379.80	221.92	2.41
LSD (p=0.05)	1.09	0.68	11.4	0.97	0.90	0.63	-	-	-	-

continuous cropping in same field the compactness of bed caused water deficit and reduced the water intake by the crop. So, there might be a competition between the crop and green manure for water which might have reduced the yield. Similar finding was reported by Hasanuzzaman (2019).

Economics

The highest B:C ratio of 3.59 was recorded in direct-seeded rice in flat bed + green manuring-okra + crop residue mulching (**Table 3**) due to higher fruit yield and maximum net return. Similar findings were also reported by Pandey *et al.*2013 that the straw mulching increases fruit yield in tomato and thereby it improved the net return.

Conclusion

Conservation agriculture practices followed in rice-okra cropping system has significant influence on weed management in okra. Direct-seeded of rice in flat bed + green manuring followed by planting of okra with minimum soil disturbance and crop residue mulch maybe recommended as an effective weed management practice for okra in a rice- okra cropping system.

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Indian Journal of Weed Science **53**(2): 169–172, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Assessment of spread of noxious Kongwa weed in Tanzania, using pathway risk analysis

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Article information

DOI: 10.5958/0974-8164.2021.00031.9

Type of article: Research article

Received : 5 February 2021
Revised : 11 June 2021
Accepted : 14 June 2021

Key words

Dissemination

Noxious Kongwa weed

Pathways

Pathway risk analysis

Risk assessment

ABSTRACT

The noxious Kongwa weed (*Astripomoea hyoscyamoides* VatkeVerdc.) has been reported to cause enormous damage to crops and pastures in various parts of Tanzania, particularly Kongwa District of Tanzania. This paper assesses spread risk of potential pathways for the entry and spread of it in Kongwa District. The research progressed in two stages- with the first stage comprising a review of relevant local and international literature on the means of weed spread. Secondly, a household survey using a semi-structured questionnaire was conducted in Kongwa district to collect data on various land use practices that are associated with the spreading of the weed. Risk assessment framework containing six criteria was applied to the identified potential pathways. Pathway risk for each pathway was evaluated and assigned an intensity rating score through an analysis of the interviewee answers using Statistical Package for the Social Sciences (SPSS) software version 26. Results showed that, the most high-risk pathways were livestock movements and stock fodder transportation (81%) and agricultural produce and inputs (77%) which was attributed to the existing land use type in Kongwa. The medium risk pathways were farming tools, equipment, machines, footwear and clothing (75%) and water dispersal (56%). The low-risk pathways were wind dispersal (44%), construction activities (43%), escape from research sites (30%), ornamental plant trade (28%), tourism (25%) and introduction via exotic plant species (20%). Based on these findings, government and other stakeholders are advised to allocate weed preventive resources in the order of the threat level posed by a particular pathway.

INTRODUCTION

Noxious weeds are large problem in many parts of the world, greatly affecting areas of agriculture, forest management, nature reserves, parks and other open space. *Astripomoea hyoscamoides* weed also known as Kongwa weed is one of the noxious weeds that have been reported to exist in Tanzania (Nkombe *et al.* 2018). The weed has been named Kongwa weed because of its severe infestation and apparent nativity in Kongwa district, Tanzania (Nkombe *et al.* 2018). *A. hyoscamoides* (Kongwa weed) is an annual dry land noxious weed having alternate simple leaves, white flowers with purple center and its height can reach up to approximately two meters at full maturity (Nkombe *et al.* 2018).

Nevertheless, because of its prolific growth, Kongwa weed has posed a serious threat to crop and forage production and subsequently affecting farmers' livelihoods (Mwalongo *et al.* 2020). Although the weed has been the subject of discussion among various media outlets and stakeholders, no studies have been conducted to ascertain the nature of its introduction and spread or to assess the relative risks of different pathways responsible for Kongwa weed spread in Kongwa district.

This study aimed to assess the risk posed by different potential pathways using a pathway risk analysis method. Pathway risk analysis method is a risk assessment approach which involves identifying a number of potential or possible pathways, assessing the threat that can be posed by each pathway and finally evaluating how each pathway can be managed with ease (Coleman *et al.* 2010). Pathway risk analysis method has proved to be an efficient way for identifying and ranking risk for various pathways, that have higher potential in spreading weeds in various areas of United States (Andow 2003), Victoria, Australia (King *et al.* 2008) and New Zealand (Williams *et al.* 2000).

MATERIALS AND METHODS

Study location and climate

The study was conducted in Kongwa district in the year 2020, where the interviews through a semi-structured questionnaire were conducted. Kongwa district is located between 5° 302 S and 6° 02 Slatitudes and 36° 152 E and 36° 02 E longitudes and is one of the seven districts making up Dodoma region in central Tanzania. Administratively Kongwa district comprises a total of 22 wards, 87 villages, 383 hamlets and 2 township authorities (URT, 2016). According to the 2012 Population and Housing Census, the population of Kongwa district was 309,973 (149,221 males and 160,752 females) (URT, 2013). The mean daily temperature in Kongwa district was 26.5°C with the highest temperature recorded being 31°C and the lowest temperature 18°C (URT, 2016). The district has a unimodal rainfall regime with the rainy season starting in December and ending in April. The average annual rainfall ranges between 500 and 800 mm (URT, 2016).

Data collection procedure

In this study, two sources of data/information were employed; the first one was a review of relevant local and international literatures to identify possible pathways for weed spread in Tanzania. The second one was a house hold survey in Kongwa district using a semi structured questionnaire to collect information on the various land use practices for pathway risk assessment. During the survey, stratified random sampling method was used to select 120 respondents from 24 villages within Kongwa district. Respondents were stratified based on their land use category and were identified with the assistance of the Agricultural Extension Officers in their respective villages. The adopted land use categorization was agriculture, livestock and residential land because these are the main land use found over the area. Agricultural Extension Officers from Mtanana and Mbande villages and other 18 residents were purposely selected to act as key informants in this survey.

Identification of pathways

Pathway has been defined as “any means that allows the entry or spread of a pest” (IPPC 2017). Studies by Mushi 2019, and Mtenga *et al.* 2019 have revealed the potential pathways that can cause weed spread in Tanzania.

Pathway risk analysis

A quantifiable risk assessment framework was developed and then applied to all pathways. The method of ranking pathways basing on their risk score was adapted and modified from the work done by King *et al.* (2008). In this method, six main criteria were developed in order to formulate the risk assessment framework. The six main criteria and weightage assigned based on methodology of King *et al.* (2008) are given in **Table 1**.

Risk assessment

Information from the conducted house hold survey was used to assess each criterion for every pathway, however the information needed to assess each criterion with respect to a certain pathway was not always available. In that regard the assessment was treated as missing data.

Assigning intensity ratings and calculation of final pathway risk score for each pathway

Each pathway was evaluated for every criterion using the following intensity ratings: Low (L=0), Medium-Low (ML = 0.25), Medium (M=0.5), Medium-High (MH=0.75), High (H = 1.0). Whereby the High (H=1) rate indicates highest risk of the pathway in spreading the weed and the Low (L=0) rate indicates lowest risk of the pathway in spreading the weed. In the moments of missing information, the criterion was removed from the analysis.

To obtain the final pathway risk score for each pathway, the following formula was applied:

$$Pathway\ Risk\ score = \sum\left((average\ intensity\ rate) \times (criterion\ weight)\right)......$$

(King *et al.* 2008)

Average intensity rate was obtained by taking the mean of intensity rating of all sub-criteria within a main criterion. Intensity rates were chosen from intensity rating score (*i.e.*, from H=1 to L=0). Criteria weights were obtained from **Table 1** (from lowest of 0.04 to highest of 0.4).

Table 1. Weights of selected criteria (King *et al* 2008)

Criteria	Weightage (percentage)
Weed importance	4
Distance (Rapidity)	8
Introduction	8
Frequency of activity	13
Establishment	40
Management	27

Furthermore, the pathways were further classified into three groups based on their risk percentage score as: High (>75%); Medium (54-75%) and Low (<54%) (King *et al* 2008).

RESULTS AND DISCUSSION

The final risk score for each pathway is shown in **Table 2** in descending order.

Table 2. Final risk score of different pathways

Pathway	Risk score (%)
Livestock movements and stock fodder transportation	81
Agricultural produce and inputs	77
Farming tools, equipment, machines, footwear and clothing	75
Water dispersal	56
Wind dispersal	44
Landscaping/Construction activities	43
Escape from research sites	30
Ornamental plant trade	28
Introduction via tourism	25
Introduction via exotic plant species	20

Table 3. Risk categorization for each pathway

Group	Pathways
High risk	Livestock movements and stock fodder transportation; Agricultural produce and inputs
Medium risk	Farming tools, equipment, machines, footwear and clothing; Water dispersal
Low risk	Wind dispersal; Landscaping/construction activities; Escape from research sites; Ornamental plant trade; Introduction via tourism; Introduction via exotic plant species

The pathways were further classified as shown in **Table 3**. The introduction of noxious weeds in an area can be a result of the changes in environmental conditions of an area, accidental or intentional introduction through human activities and/or natural means such as water and wind dispersal (Bhowmik 2014).

Among the various investigated potential pathways, livestock movements and stock fodder transportation were found to be the pathways which posted the highest risk (81%) for the spread of the Kongwa weed as shown in **Table 2**. This result can be explained first by the nature of the major land use practice in Kongwa district which is largely mixed agriculture (URT, 2016) and second by the data collected during the interviewing of the land users in the infested land in Kongwa district. The interview results showed that 74.6% of livestock keepers use agro-pastoralism livestock keeping system, with 96.6% of them not taking any precaution to quarantine their livestock arriving from suspected infested lands and 100% of them not taking any hygienic measures to livestock before leaving suspected infested pasture land or before arriving in weed free areas. Livestock mobility and crop residue feeding have been used by pastoralists as drought coping strategies where animals get access to high quality forage resources and water (Vetter 2005). Livestock movement and stock fodder transportation have been reported to be the major pathway for the spread of weeds in agro-pastoral societies (Zhu *et al.* 2019).

The other pathway which posed high risk for the spread of the Kongwa weed was agricultural produce and inputs. Usually, Kongwa weed reaches maturity stage at the same time with most of the crops like maize, sorghum, millet and sunflower(*i.e.*, around April-June). Because of that, there is a greater risk of harvesting contaminated crops. This is supported by the results from the interviews which indicate that 70.9% of the farmers do not take any measures to control Kongwa weeds on their crop farms. Moreover, the results from the interviews indicate that 73.3% of the farmers use uncertified crop seeds. This may pose greater risk of planting seeds contaminated with Kongwa weed seeds because 79% of the farmers keep seeds from the previous harvest for the next growing season. Agricultural produce and inputs have been reported to pose greater risk for spreading weed seeds in several other studies (Rao *et al.* 2017).

Water dispersal (hydrochory) has been reported to be an important pathway for spreading weed seeds and propagules (Benvenuti 2007). Results from this study indicate that water dispersal pathway poses medium risk in the spread of Kongwa weed. This can be explained in part by the nature of the Kongwa weed seeds which have been observed (through field observations) to lack buoyancy, a property essential for seeds to float in water over long distances. Weed seeds need to have buoyancy characteristics to enable them to float in water over long periods of time and be transported over long distances (Fernández 2019 and Shi *et al.* 2020).

Farming tools, equipment, machines, footwear, and clothing have been assessed to pose medium risk for spreading Kongwa weed. This is apparent from the interview results which show that about 95.8% of all the land users in Kongwa district do not take hygienic measures on themselves and tools when entering or leaving infested lands. Kongwa weed seeds can attach themselves to clothing, or stick to footwear, farming tools, tractor tires or harvesting machines where they can be transported to other weed free areas and thereby start new infestation.

On the other hand, the wind dispersal pathway was assessed to pose low risk in spreading the Kongwa weed based on the biological characteristics of the Kongwa weed seeds. Weed seeds need to have special features such as lateral wings or pappus, hairs of feather and very lightseed weight for them to be able to be transported by winds over long distances

(Bryson and Carter 2004). Kongwa weed seeds are devoid of such characteristics. Furthermore, Kongwa weed seeds have been observed to fall very near to their plant stems and therefore very unlikely to be carried over long distances by wind (Nkombe *et al.* 2018). Other pathways that fell under the group of low-risk pathway are; landscaping/construction activities, escape from research sites, ornamental plant trade, introduction via tourism and introduction via exotic plant species. The major reason for these pathways to pose low risk was the low frequency of operation per year of these pathways (Randall 2014).

In an effort to prevent or reduce the spread of weeds, the first step invariably involves awareness of the various pathways at play in the spread of the weeds. This study results indicate the need for preventive measures to be initiated both at national and individual level because as always prevention is cheaper and much better than eradicating weeds after they have long established. At national level, there is a need for formulation of a national weed strategy with an objective to increase awareness of the impacts of the weeds to private and public land holders and establish a mechanism to effectively share early warnings information on introduction of noxious weeds. The strategy should also ensure proper cooperation and participation among government officials, farmers and other stakeholders in managing weeds across Tanzania's landscape. It is recommended for livestock keepers to reduce livestock movements through improved forage resources via pasture establishment or enclosure management.

ACKNOWLEDGEMENT

The authors' great appreciation goes to Tanzania Meteorological authority (TMA), European Union (EU) through Erasmus Mobility project and COSTECH, through the research project on "*Enhancing Rangeland Productivity and Community Livelihoods through Integrated Management of Noxious Weeds in Kongwa District*" for providing funds to assist in the accomplishment of this work.

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Indian Journal of Weed Science **53**(2): 173–178, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Development of small tractor operated boom sprayer for effective control of weeds in maize

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Article information

DOI: 10.5958/0974-8164.2021.00032.0

Type of article: Research article

Received : 8 February 2021
Revised : 21 May 2021
Accepted : 24 May 2021

Key words
Boom sprayer
Hollow cone nozzle
Small tractor
Volume mean diameter
Weed control efficiency

ABSTRACT

The application of pesticides is one of the important aspects of a crop production system. The development of a single spraying system for all types of pesticide application is a solution for a cost-effective and efficient crop production system. Standardizing the droplet sizes at different operating pressure of hollow cone nozzle will be a solution for controlling the weeds as well as the other pests. A small tractor-operated hollow cone-based boom sprayer was developed to overcome said problems. The developed sprayer can be mounted on three-point linkage and can be operated by tractor PTO. The developed system was evaluated for 0.1, 0.2 and 0.3 MPa of operating pressure through water-sensitive papers and ImageJ software. Under this pressure, the selected hollow cone nozzle produced medium to coarser droplet size. The highest VMD of 346.4 µm was obtained under operating pressure of 0.1 MPa and the least VMD of 277.1 µm was obtained under operating pressure of 0.3 MPa. The increase in operating pressure causes a reduction in droplet size. However, the relative span (RS) was increasing with a decrease in operating pressure. It was 0.72 at an operating pressure of 0.3 MPa and increased to 1.27 at an operating pressure of 0.1 MPa. The highest weed control efficiency (WCE) of 88.1% was obtained under 0.1 MPa of operating pressure. However, the operating pressure does not had significant effect on WCE.

INTRODUCTION

Pesticide application remains an important component of agricultural production system (Jyoti *et al.* 2017 and 2019). Furthermore, chemical application inhibits the growth of weeds, pests and diseases, ultimately reducing crop and fruit yield losses. Though, pests, weeds and diseases pose a severe impact on the production and quality of agricultural produce (Tewari *et al.* 2014a, Chandel *et al.* 2018) nevertheless, the increased use of pesticides as well as efficient utilization of plant protection equipment plays a significant role to control diseases, pests and weeds by dispensing, distributing and depositing recommended doses of chemicals on the intended target (Tewari *et al.* 2014b, Jyoti *et al.* 2020). Chemical application via plant protection equipment is the most practiced method because of its ease in operation and economical aspects. Despite being the commonly used method, chemical application by means of plant protection equipment leads to extensive dispersion of harmful chemicals in the environment (Kumar *et al.* 2020). These traditional pest management techniques involve human drudgery and higher operational cost compared to tractor-drawn chemical spraying systems (Chethan and Krishnan 2017, Chethan *et al.* 2018, Kumar *et al.* 2019).

The main challenge in plant protection through spraying equipment involves ground surface deposition and off-target drift. This drift often results in a source of environmental pollution and a threat to human and animal health (Maski and Durairaj 2010). To mitigate the said problem and achieve uniform deposition, distribution and uniform vertical fluid distribution, a tractor-based spray application system can be encouraged (Sedlar *et al.* 2013). Government, agricultural research organizations and agricultural machinery manufacturers have a serious challenge developing agricultural technologies suitable for small and marginal farmers. The developed implements and machinery should reduce drudgery and enhance crop productivity. Hence, the use of tractor-operated time-saving equipment needs to be promoted (Raut *et al.* 2013).

Developing a spray application system as an attachment for a small tractor can offer a solution to the above-cited problem. Therefore, an efficient single spraying system needs to be developed which can be suitable for spray of insecticides, fungicides and herbicides with easy attachment of flat fan, flood jet nozzles, hollow cone and solid cone nozzles (Chethan *et al.* 2019). However, the hollow cone nozzles are used in some cases of herbicide applications with droplet sizes ranging from medium to coarser (ASABE 2009, Hartzler 2016). Hence, the present study was undertaken to develop a mechanical power-based universal spray application system and evaluated for herbicide application in maize crops.

MATERIALS AND METHODS

Development of "Small tractor operated boom sprayer"

A small tractor (22 hp) operated boom sprayer system was developed for field crops at ICAR-Central Institute for Agricultural Engineering, Bhopal (23°182 36.693 N, 77°242 17.683 E) (**Figure 1**). The spraying system consists of storage loft tank having 300 liters of capacity and made of polyethylene plastic material, HTTP horizontal triplex axial piston pump, hollow cone nozzles, pressure regulating valve, strainer, boom, pressure gauge, and hose pipe. The pump discharges 36 lpm at 28 bar pressure and 950 rpm. Spray control valves were provided with a spring-loaded ball that opens as pressure increases, so the excess flow will be bypassed back to the tank to prevent damage to the sprayer components when the boom is closed. The pump discharge was connected with the tank and nozzles boom through hose pipes. A strainer was used between suction line of the tank and pump. The filter of mesh size 16 to 80 meshes were used to filter out unwanted materials from spraying solution. The mesh size of the filter (>50) refers to the opening per linear inch in the screen (Grisso *et al.* 2014).

The hollow cone nozzle was selected to standardize the developed spraying system to apply herbicide, insecticide and fungicide (Grisso *et al.* 2019). The main use of hollow cone nozzle is in application of insecticide and fungicide, however, in some cases; it is also used for herbicide application under lower operating pressure and medium to coarser spray droplet size (ASABE 2009, Chethan *et al.* 2019). The developed sprayer will be mounted on three-point linkage and will drive by tractor PTO. The pump was fixed over the drawbar and driven by the PTO of the tractor by belt pulley arrangement. The loft tank was fitted as the tractor roof canopy or ROPS (rollover protective structure). The total length of the boom was 7 m. A flexible type hinge was fabricated to achieve a five folded boom system. The fold system is arranged in such a way that the spray boom can be fixed in horizontal as well as vertical positions based on crop canopy geometry. A three-point linkage system was fabricated to mount the nozzles boom at a variable height according to crops height.

Evaluation of developed boom sprayer under laboratory

The developed spraying system was calibrated in the laboratory. The calibration of nozzles was carried out at different pump pressure and engine rpm. The pressure of the pump was maintained with the help of pressure regulating valve at different engine rpm with the help of the throttle lever of tractor. The experiment of the calibration was carried out at three pressure levels, 0.1, 0.2 and 0.3 MPa. The spraying system was operated at different pump pressure and their corresponding discharge was recorded.

Spray droplet characteristics were taken using water-sensitive paper (WSP). Under the laboratory, the WSPs were fixed on metal sheets with the help of paper clips. These WSPs fixed system and was placed at the center of swath and at 500 mm below the nozzle tip. After applying the herbicide, the WSPs

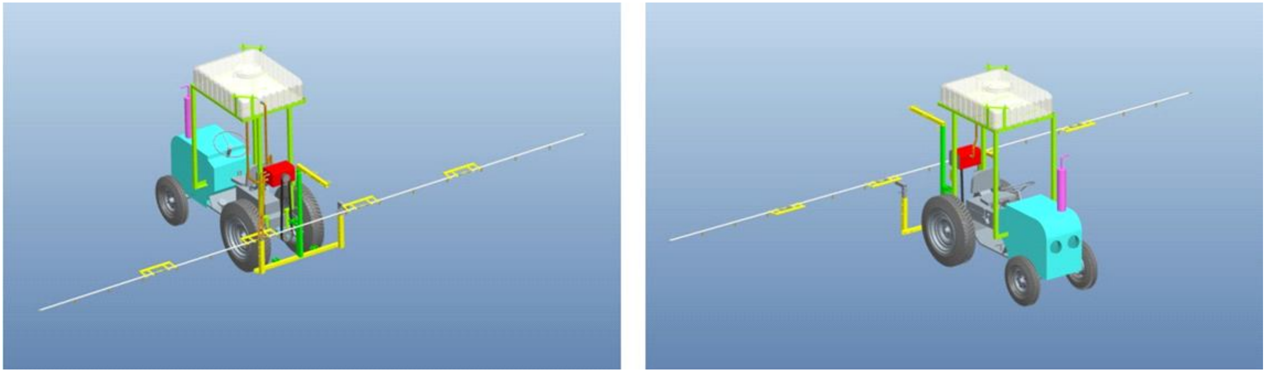


Figure 1. CAD diagram of developed small tractor operated boom sprayer

were collected immediately and placed in a darker box to avoid volatilization losses. Later, the WSPs were scanned with the help of a scanner and saved in a JPGE file of 600dpi. The spray droplet analysis was carried out in the laboratory by using scanned images with the help of ImageJ software (Lv *et al.* 2019, Ozluoymak *et al.* 2019). The ImageJ is Java-based image-processing software used for acquisition and analysis of images. The different spray performance parameters, *viz.* spray rate, DV_{10}, DV_{50}, DV_{90}, number median diameter (NMD), droplets density (droplets/cm^2), coverage (%), mean diameter and standard deviation (SD) were determined by analyzing spray traces collected on water-sensitive papers (Lv *et al.* 2019, Longo *et al.* 2020). Also the relative span (RS) a dimensionless number was also calculated to obtain the spray uniformity (Simão *et al.* 2020). The RS is used to estimate the distribution spread and homogeneity of spray application. It is calculated by using the following formula.

$$RS = \frac{(D_{90}-D_{10})}{D_{50}} \qquad \text{--- (Eq.1)}$$

Evaluation of developed boom sprayer under field condition

The developed small tractor operated boom sprayer was evaluated in maize crop during *Rabi* 2020-21 at research farm of ICAR-Central Institute for Agricultural Engineering, Bhopal. A field was prepared by 2 times passing of rotavator and one time passing of leveler. The maize crop was sown at a row spacing of 450 mm and plant to plant spacing of 250 mm. The developed boom sprayer was attached to a small tractor and was operated at 2.5 km/h speed of operation to achieve the target application rate of 375 l/ha (**Figure 2**).

The weed floral data was recorded from testing field at 60 DAS. To check the weed control efficiency and effectiveness (WCE) of the developed boom sprayer, the weed floral data was compared with the weedy plot. The weed control efficiency was calculated by using the following formula (Chethan *et al.* 2020).

Figure 2. Field evaluation of developed "Small tractor operated boom sprayer"

$$WCE = \frac{(W_c-W_t)}{W_c} \times 100 \qquad \text{--- (Eq.2)}$$

Where W_c and W_t are weed dry weight in weedy and herbicide applied plots, respectively.

Statistical analysis

The obtained parameters under laboratory were analyzed using a CRD design and field evaluation parameters were analyzed using RBD. Evaluation of the system was replicated thrice and was analyzed in SAS software (Version 9.4M7 / August 18, 2020, SAS Institute, US). The inferences were drawn at a 5% level of significance.

RESULTS AND DISCUSSION

Effect of operating pressure on droplet size

The operating pressure of the spraying system had a significant effect on droplet size, produced from the developed spraying system (**Table 1** and **Figure 3**). During testing of developed boom sprayer, the nozzle holding height was maintained constant to obtain spray uniformity. The spray droplet accumulated on WSPs, analyzed by ImageJ is Java-based image-processing software (Fig.4) that clearly differentiates the effect of operating pressure on the droplet size. When effect of droplet size on herbicide efficacy is considered, the Volume Mean Diameter (VMD) *i.e.*VD_{50} plays a very important role (ASABE 2009, Chethan *et al.* 2019).

The highest VMD of 346.4 µm was recorded under operating pressure of 0.1 MPa, followed by 313.5 µm at operating pressure of 0.2 MPa and 277.1 µm at operating pressure of 0.3 MPa. The higher operating pressure caused the reduction of droplets size and increases the droplet number (**Figure 5**). The droplets obtained under the operating pressure of 0.1 and 0.2 MPa are classified as coarse and droplets obtained in 0.3 MPa classified as medium. It is recommended that the medium to ultra-coarse droplet size is best suited for herbicide application (ASABE 2009, Chethan *et al.* 2019). The RS was increasing with a decrease in operating pressure (**Table 1**). It shows that a higher degree of homogeneity at lower operating pressure.

The lowest VMD was found at operating pressure of 0.3 MPa, which was 19.98% and 11.46% lower than VMD at operating pressures of 0.1 and 0.2

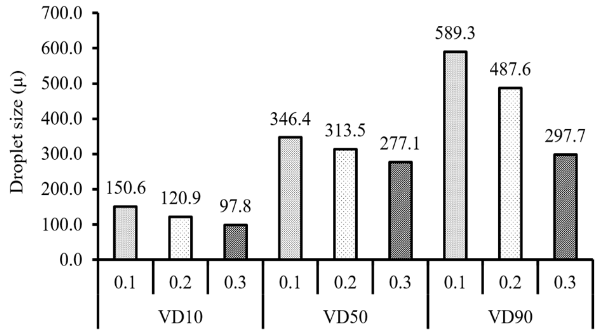
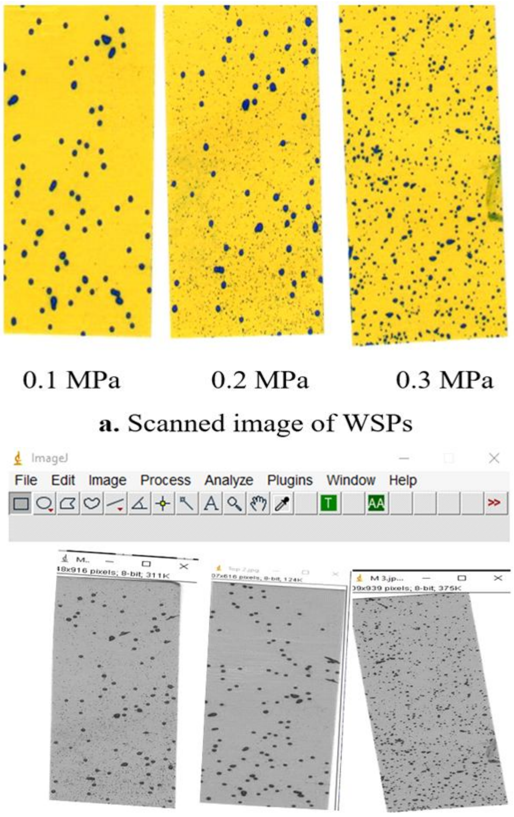


Figure 3. Spray droplet size obtained under different operating pressure



b. WSPs images analyzed in ImageJ software

Figure 4. Droplet size obtained under different operating pressure

Table 1. Effect of operating pressure on droplet size diameter and weed dry weight

Operating pressure (MPa)	Droplet size (µm)			Relative span	Weed dry weight	WCE (%)
	VD_{10}	VD_{50}	VD_{90}	RS	(g/m^2)	
0.1	150.6	346.4	589.3	1.27	1.64 (2.27)	88.1
0.2	120.9	313.5	487.6	1.17	1.94 (3.29)	85.9
0.3	97.8	277.1	297.7	0.72	2.13 (4.21)	84.5
LSD (p=0.05)	1.687	1.458	0.840	0.003	1.11	NS

*Weed data subjected to square root transformation $\sqrt{x+0.5}$; original data is in parentheses

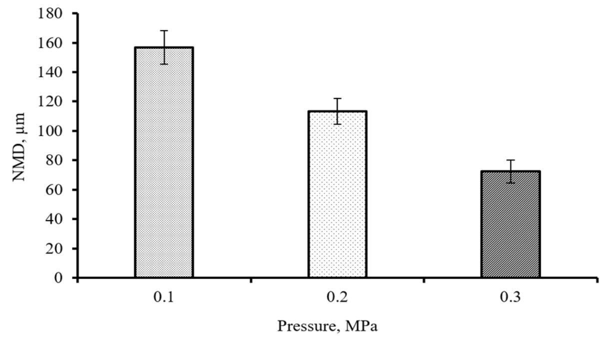


Figure 5. NMD of the droplets obtained under different operating pressure

MPa respectively. It has been noted that through a wide range of atmospheric conditions, droplets with diameters greater than 140 µm show little tendency to drift (Thread gill *et al.* 1975). The VMD at 0.2 MPa was 9.5% lesser compared to VMD at 0.1 MPa. The average droplet size was found to be decreased with an increase in operating pressure during the spraying process (Alheidary *et al.* 2019).

The number median diameter (NMD) was found to be decreased from 156.48 µm (SD: ±11.4), 113.6 µm (SD: ±8.7) and 72.4 µm (SD: ±7.9) for the increased pressure level of 0.1, 0.2 and 0.3 MPa, respectively. The lowest NMD was found to be 72.4.8 ìm, at the operating pressure of 0.3 MPa, which was 53.82% lower than NMD at operating pressures of 0.1 MPa for fixed nozzle height of 500 mm (**Figure 4**). The NMD at 0.2 MPa was found to be 27.67% lower compared to the operating pressure of 0.1 MPa.

Effect of operating pressure on droplets density and coverage

The droplets density and coverage were also analyzed from WSPs. **Figure 3, 4** and **5** show a significant effect of the operating pressure on the mean of the droplet density and coverage. It was observed that a constant nozzle height of 500 mm resulted in a considerable increase in droplets density (**Figure 6a and b**).

The droplet density was found to be increased by 42.76% and 100.28% at operating pressure of 0.2 and 0.3 MPa compare to 0.1 MPa. The reason for the increase in droplet number may be due to a decrease in the mean of the droplet sizes. The droplet density was found to be 105.7 (SD: ±9.4), 150.9 (SD: ±12.3) and 211.7 (SD: ±14.7) deposit/cm^2 at operating pressure of 0.1, 0.2 and 0.3 MPa of operating pressure. The effect of operating pressure at droplet density is shown in **Figure 5**. The coverage of droplets was found to be increased with an increase in operating pressure. Coverage was 30% (SD: ±3.5),

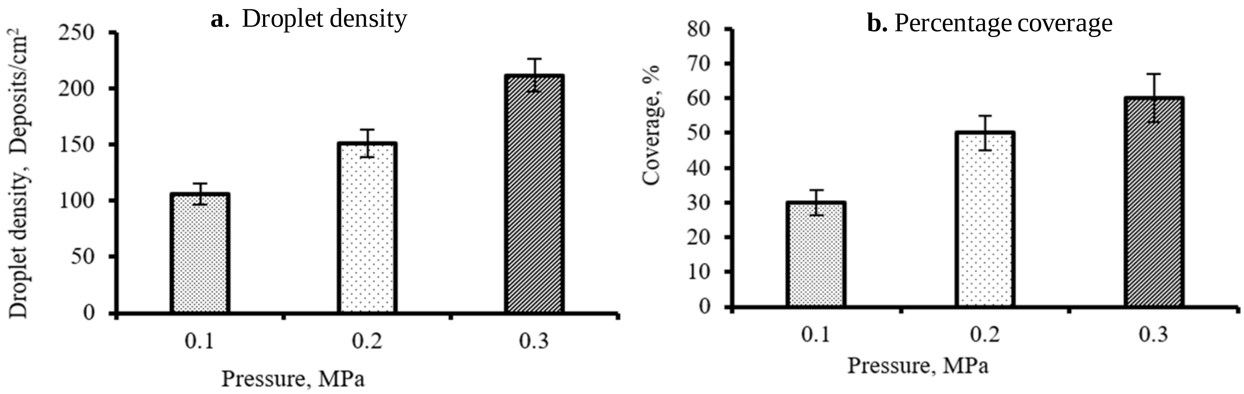


Figure 6. Effect of operating pressure on droplet density and percentage coverage

50% (SD: ±5.1) and 60% (SD: ±6.9) at operating pressure of 0.1, 0.2 and 0.3 MPa, respectively. The coverage percentage was found to be increased by 66.67% at 0.2 MPa and 100% at 0.3 MPa compare to 0.1 MPa of operating pressure. This result agreed with the studies of Taylor *et al.* (2004) and Yashiro *et al.* (2012). The spraying system was operated in the field at 0.3 MPa operating pressure due to effective VMD, droplets deposition and coverage.

Effect of herbicide application at different operating pressure on weed control

The selected treatments for field evaluation include application of herbicide at operating pressure of 0.1, 0.2 and 0.3 MPa and the results were compared with the weedy plot where herbicide was not applied. The major weed flora observed in the testing plots were *Lathyrus aphaca, Vicia sativa, Chenopodium album, Medicago polymorpha* and others. A significantly highest weed dry weight of 13.78g/m^{2}was recorded in weedy plots, while the least dry biomass was observed in herbicide applied plots (**Table 1**). The weed control efficiency (ECE) was not affected by the operating pressure (**Table 1**). However, the highest weed control efficiency of 88.1% was obtained in 0.1 MPa operating pressure followed by 85.9% at0.2 MPa. The least WCE was obtained in 0.3 MPa of operating pressure.

Weeds are effectively controlled when larger droplet sizes (coarser) are generated at lower operating pressure. It is because, at coarser droplet size, spray drift was minimum and applied herbicide reached the target (Simão *et al.* 2020). Thus, higher WCE was obtained at 0.1 MPa is that over 0.2 and 0.3 MPa. The same is the case when a comparison was made between the 0.2 and 0.3 MPa. Thus, the hollow cone nozzle also can be used to control weeds effectively at operating pressure from 0.1 to 0.3 MPa.

Field evaluation and cost economic

The average height of maize crops during testing was 340±32 mm. The total length of the boom was 7 m with 15 hollow cone nozzles. The fold system was designed in such a way that the spray boom can be fixed in horizontal as well as vertical displacement according to the need of crop canopy geometry. The theoretical and effective field capacity of the sprayer was measured as 1.8 ha/h and 1.45 ha/h, respectively, at a forward speed of 2.8 km/h. The field efficiency of the sprayer was 73% due to the loss of time in tank filling. The area covered by one time of filling of the tank (300 L) was 0.57 ha. The average fuel consumption was 3.5 L/h. The cost of the spraying system was calculated as ₹ 30000. The cost of operation of a sprayer with a tractor was calculated by considering the fixed and variable cost of the tractor and sprayer. Assuming the appropriate rate of depreciation, interest on investment, housing, insurance and taxes and calculating the cost of fuel, lubricants, operator wages, repair and maintenance charges, the cost of operation of developed tractor operated sprayer costs 500 ₹/ha (exclusing the cost of chemicals).

Conclusions

A small tractor-operated boom sprayer was developed for small and marginal land holding farmers. The spraying can be done at different heights above the crop canopy surface. The system was compact in design and easily attached with a small tractor three-point linkage. The droplet characteristics were decided at different pressures and found that 0.1 to 0.3 MPa was suitable for applying the herbicide through a hollow cone nozzle. The effective field capacity and field efficiency of the sprayer was measured as 1.45 ha/h and 73%, respectively. The cost of operation of tractor operated sprayer has amounted to 500 ₹/ha.

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Indian Journal of Weed Science **53**(2): 179–181, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Performance of herbicides and herbicide mixtures on weed control in transplanted rice

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Article information

DOI: 10.5958/0974-8164.2021.00033.2

Type of article: Research note

Received : 5 October 2020
Revised : 2 April 2021
Accepted : 4 April 2021

Key words

Herbicide mixtures, Transplanted rice, Weed control efficiency, Weed density, Weed dry-weight

ABSTRACT

The information on efficacy of new low-dose herbicides and herbicide mixtures is very limited in transplanted rice. An experiment was conducted, to study the effect of herbicides and herbicide mixtures on weed control in transplanted rice. Lower weed density and dry weight was recorded with florpyrauxifen-benzyl + cyhalofop-butyl and penoxsulam + cyhalofop-butyl which was at par with hand weeding at 20 and 40 DAT. Herbicide mixtures were more effective to control weeds than single application of either pre- or post-emergence herbicides. Higher grain and straw yields were obtained with florpyrauxifen-benzyl + cyhalofop-butyl EC 150 g/ha PoE *fb* hand weeding at 40 DAT which was comparable to minimum competitive plot.

Rice (*Oryza sativa* L.) is the most important staple food for more than half of the world population. Rice is cultivated in different ecosystems to increase production levels due to climate change. Though different ecosystems are emerging day by day but, transplanting is the most dominant and traditional method of rice cultivation under irrigation. Weeds are the major constraints in rice production. Transplanted rice is infested by heterogeneous type of weed flora which causes yield reduction about 33-45% (Duary *et al*. 2015). Due to usage of single herbicide the complex weed flora was not controlled effectively (Mohapatra *et al*. 2017). In order to control heterogeneous type of weed flora and to prevent development of herbicide resistance, there is need to depend on low dose herbicides and herbicide mixtures. The information on low dose herbicides and herbicide mixtures is very scanty. Therefore, to fulfill the above gaps, the present investigation was undertaken to test the effect of new herbicides and herbicide mixtures on weed control of transplanted rice.

A field experiment was conducted at Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad during *Kharif*, (rainy Season) 2019. The farm is geographically situated at 17 ^{0}19' 16.4" North latitude and 78^0 24' 43" East longitudes and at an altitude of 542.3 m above mean sea level. According to Troll's climatic classification, it falls under semi- arid tropics (SAT). The soil of experimental site was sandy loam in texture with p^H of 7.85, low in available nitrogen (235.2 kg/ha), high in available phosphorus (38.8 kg/ha) and available potassium (379 kg/ha) contents. The experiment consisted of 12 weed management practices laid out in randomized block design with three replications. '*RNR–15048*' (*Telangana sona*) variety was transplanted in main field at the age of 28 days old seedlings with a spacing of 15× 10 cm. All pre-emergence herbicides were applied within three days after transplanting and post-emergence herbicides were applied at 2–3 leaf stage of weeds. All other management practices were done as per recommendations given by PJTSAU. Density of weeds, *viz*. grasses, sedges and broad-leaved weeds were recorded by using of 50 × 50 cm quadrat and dry weight of weeds was recorded from 50 × 50 cm area by destructive sampling. Weed control efficiency (WCE) was calculated based on weed dry weight. The data on weed density and dry weight for all the categories were computed using square root $(\sqrt{x+1})$ transformation.

Effect on weeds

The weed species found in the experimental field were *Echinochloa colona, Echinochloa crus-galli,*

Table 1. Effect of herbicides and herbicides mixtures on density and dry weight of weeds in transplanted rice at 30 DAT

Treatment	Weed density (no./m^2)			Total weed density (no./m^2)	Total weed dry weight (g/m^2)
	Grasses	Sedges	BLW		
Penoxsulam 0.97% + butachlor 38.8% SE 820 g/ha PE *fb* HW at 30 DAT	3.0(8.3)	2.6 (5.7)	2.4(5.0)	4.5(19.0)	3.9(14.5)
Pyrazosulfuron-ethyl 0.15% + pretilachlor 6% GR 600 g/ha PE *fb* HW at 30 DAT	2.8(6.7)	2.3 (4.3)	2.4(4.7)	4.1(15.7)	3.8(13.3)
Orthosulfamuron + pretilachlor 6% GR 600 g/ha PE *fb* HW at 30 DAT	3.1(8.3)	2.3 (4.3)	2.6(5.70)	4.4(18.3)	3.9(14.0)
Ipfencarbazone 25% SC 156.25 g/ha PE *fb* HW at 30 DAT	3.2(9.0)	2.4 (4.7)	2.9 (7.3)	4.7(21.0)	4.2(16.8)
Penoxsulam 2.65% OD 25 g/ha PoE *fb* HW at 40 DAT	3.3(10.0)	2.6 (6.0)	2.9 (7.7)	5.0(23.7)	4.3(18.0)
Penoxsulam 1.02% + cyhalofop-butyl 5.1% OD 150 g/ha (PoE) *fb* HW at 40 DAT	2.2(4.0)	1.9 (2.7)	2.0(3.0)	3.3(9.7)	2.9(7.4)
Pretilachlor 50 % EC 0.75 kg/ha PE *fb* 2,4 D 1.0 kg/ha PoE	3.6(12.3)	3.4(10.7)	1.7 (2.0)	5.1(25.0)	4.5(19.2)
Bispyribac-sodium 10% SC 25 g/ha PoE *fb* HW at 40 DAT	3.4(10.7)	2.7 (6.3)	2.9 (7.3)	5.0(24.3)	4.4(18.6)
Florpyrauxifen-benzyl + penoxsulam 12% EC 40.64 g/ha (PoE) *fb* HW at 40 DAT	2.3(4.3)	2.0 (3.0)	1.9 (2.7)	3.3(10.0)	2.9(7.7)
Florpyrauxifen-benzyl + cyhalofop-butyl 10% EC 150 g/ha PoE *fb* HW at 40 DAT	2.2(3.7)	1.6 (1.7)	2.1 (3.3)	3.1(8.7)	2.7(6.3)
Hand weeding at 20 and 40 DAT	1.9 (2.7)	1.4 (1.3)	2.1 (3.3)	2.8(7.3)	2.6(6.0)
Unweeded control	5.0(24.0)	5.2(26.3)	5.0(23.7)	8.7(74.0)	8.2(65.7)
LSD (p=0.05)	0.39	0.52	0.42	0.53	0.51

Data were subjected to square-root ($\sqrt{x+1}$) transformation and original values are shown in parentheses, DAT- Date after transplanting

Paspalum distichum and *Cynodon dactylon* among grasses, *Cyperus difformis*, *Cyperus iria* and *Fimbristylis dichotoma* among sedges and among the broad-leaved weeds *Eclipta alba*, *Ammania baccifera* and *Caesulia axillaris.* All the weed management practices significantly reduced weed population and weed dry weight over unweeded control (**Table 1**).

Lower grass weed density and sedge weed density was recorded with hand weeding at 20 and 40 DAT which is statistically at par with flopyrauxifen-benzyl + cyhalofop-butyl EC 150 g/ha PoE, penoxsulam + cyhalofop-butyl OD 150 g/ha PoE *fb* hand weeding at 40 DAT and broad-leaved weeds were lower with pretilachlor EC 0.75 kg/ha PE *fb* 2,4–D WP 1.0 kg/ha PoE which was statistically at par with florpyrauxifen-benzyl + penoxsulam EC 40.64 g/ha PoE, hand weeding at 20 and 40 DAT, penoxsulam + cyhalofop-butyl OD 150 g/ha PoE and flopyrauxifen-benzyl + cyhalofop-butyl EC 150 g/ha PoE *fb* hand weeding at 40 DAT 2,4–D is selectively broad-leaved weed killer results in lower broad-leaved weeds. Similar findings were reported by Singh *et al.* (2010). The lowest total weed density and dry weight of weeds was observed in case of hand weeding at 20 and 40 DAT which is statistically at par with florpyrauxifen-benzyl + cyhalofop-butyl EC 150 g/ha PoE, penoxsulam + cyhalofop-butyl OD 150 g/ha PoE and flopyrauxifen-benzyl + penoxsulam EC 40.64 g/ha PoE *fb* hand weeding at 40 DAT. Lower weed density and dry weight was observed with application of herbicide mixtures compared to single herbicide. It might be due to effective control of complex weed flora by two different modes of action. These results were in tune with the findings of Yakadri *et al.* (2016) and Mohapatra *et al.* (2017). Higher weed control efficiency and lower weed index was observed with flopyrauxifen-benzyl + cyhalofop-butyl EC 150 g/ha PoE *fb* hand weeding at 40 DAT which was statistically at par with hand weeding at 20 and 40 DAT. It might be due to effective control of weeds during critical period of weed competition. Similar findings were reported by Saranraj *et al.* (2018) and Sreedevi *et al.* (2018).

Effect on yield

Higher grain and straw yields were recorded with hand weeding at 20 and 40 DAT which was statistically at par with florpyrauxifen-benzyl + cyhalofop-butyl EC 150 g/ha PoE, penoxsulam + cyhalofop butyl OD 150 g/ha (PoE) and florpyrauxifen-benzyl + penoxsulam EC 40.64 g/ha PoE *fb* hand weeding at 40 DAT. These treatments followed by pre-emergence application of pyrazosulfuron-ethyl + pretilachlor, orthosulfamuron + pretilachlor and penoxsulam + butachlor *fb* hand weeding at 30 DAT. There was 56.3% reduction in grain yield under unweeded control over hand weeding. Weed management practices not only reduced weed density and dry matter but also allows the plant to use available resources efficiently which resulted higher yield over unweeded control. Similar results were reported by Choudhary and Dixit (2018) and Kashid (2019).

It was conducted that application of herbicide mixture florpyrauxifen-benzyl + cyhalofop-butyl EC 150 g/ha PoE *fb* hand weeding at 40 DAT was the most effective in reducing the density and dry weight of weeds in transplanted rice at critical stage of crop-weed competition which resulted in more yields than rest of weed management practices.

Table 2. Effect of herbicides and herbicide mixtures on weed control efficiency, weed index and yield of transplanted rice

Treatment	WCE (%)	WI (%)	Grain yield (t/ha)	Straw yield (t/ha)
Penoxsulam 0.97% + butachlor 38.8% SE 820 g/ha PE *fb* HW at 30 DAT	77.98	16.7	5.93	7.00
Pyrazosulfuron-ethyl 0.15% + pretilachlor 6% GR 600 g/ha PE *fb* HW at 30 DAT	79.81	15.5	6.02	7.04
Orthosulfamuron + pretilachlor 6% GR 600 g/ha PE *fb* HW at 30 DAT	78.69	16.1	5.98	7.01
Ipfencarbazone 25% SC 156.25 g/ha PE *fb* HW at 30 DAT	74.38	22.4	5.52	6.47
Penoxsulam 2.65% OD 25 g/ha PoE *fb* HW at 40 DAT	72.65	22.8	5.50	6.42
Penoxsulam 1.02% + cyhalofop-butyl 5.1% OD 150 g/ha (PoE) *fb* HW at 40 DAT	88.74	1.9	6.98	7.82
Pretilachlor 50 % EC 0.75 kg/ha PE *fb* 2,4 D 1.0 kg/ha PoE	70.73	26.1	5.26	6.19
Bispyribac-sodium 10% SC 25 g/ha PoE *fb* HW at 40 DAT	71.74	25.1	5.33	6.28
Florpyrauxifen-benzyl + penoxsulam 12% EC 40.64 g/ha (PoE) *fb* HW at 40 DAT	88.33	3.6	6.87	7.71
Florpyrauxifen-benzyl + cyhalofop-butyl 10% EC 150 g/ha PoE *fb* HW at 40 DAT	90.36	1.1	7.04	7.92
Hand weeding at 20 and 40 DAT	90.92	-	7.12	7.99
Unweeded control	-	56.3	3.11	4.22
LSD (p=0.05)			0.43	0.50

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Indian Journal of Weed Science 53(2): 182–187, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Efficacy of carfentrazone, mesosulfuron + iodosulfuron and 2,4-D ester against *Rumex* spp. in wheat

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Article information

DOI: 10.5958/0974-8164.2021.00034.4

Type of article: Research note

Received : 5 April 2021
Revised : 25 June 2021
Accepted : 28 June 2021

Key words
2,4-D ester

Carfentrazone

Chlorophyll fluorescence

Mesosulfuron + iodosulfuron

Rumex spp.

ABSTRACT

Rumex spp. is the major broad-leaf weed of irrigated wheat. Manual weeding is not feasible in wheat crop sown with a narrow spacing and weed management thus is accomplished through application of herbicides. The poor efficacy of otherwise effective herbicides so far against this weed has come to the fore indicating the likelihood of herbicide resistance. Hence, the present study was carried out during *Rabi* of 2017-18 at screen house of College of Agriculture, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India to evaluate herbicide resistance in *Rumex* spp. and its management in wheat crop using four test populations of *Rumex* spp. named as HHH (HAU Hisar), UPH (Ujha, Panipat), JHH (Jind), and JJR (Jhajjar). Three herbicides - carfentrazone, mesosulfuron + iodosulfuron and 2,4-D ester at three doses (0.5X, X and 2.0X) with one unsprayed control were taken as treatments in the pot experiment under completely randomised design (CRD) replicated thrice. Results indicated that all the populations have attained resistance against mesosulfuron + iodosulfuron even at double of the recommended dose. Higher values of plant height, chlorophyll fluorescence, dry weight and lower value of electrical conductivity was observed in mesosulfuron + iodosulfuron treated plants. Carfentrazone provided moderate control to all populations even at double of the recommended dose. The application of 2,4-D ester at double of the recommended doses provided 77-100% control of all populations except UPH where lower efficacy continued even at double dose. Resistance thus confirmed in *Rumex dentatus* requiring alternate herbicides for field level effective management.

Wheat (*Triticum aestivum* L.) is most important cereal crop and constitutes an integral component of food security system of several countries. At world level, it is grown in approximately 214 m ha area with production and productivity of 734 mt and 3425 kg/ha, respectively (FAO STAT, 2018). In India, it is the second most important food crop after rice with an annual production of 99.8 mt in an area of 30.6 mha with average productivity of 3220 kg/ha (Anonymous, 2018). Haryana is the major wheat growing state of India with an area of about 2.5 mha with 11.7 mt production and 4.6 t/ha productivity (Anonymous 2018).

Weeds cause significant losses in wheat productivity besides lowering down the quality of produce (Malik and Singh 1995, Singh *et al.* 1999) and also they have inhibitory effects on crop growth. Weeds causes yield losses of 15-50% in wheat crop (Jat *et al.* 2003, Singh *et al.* 1999). Extent of yield loss depends upon type and density of weed, soil characteristics and environmental conditions (Malik and Singh, 1995, Chhokar and Malik 2002). Weeds affect the crop yield by competing it with for light, nutrients, moisture and space (Singh and Singh 2005 and Singh 2007). In some cases, weeds may dominate to the extent of causing complete crop failure (Malik and Singh 1995, Singh *et al.* 1999). Weed stage, herbicide rates and fertilizers application impact weed control and crop-weed competition (Singh *et al.* 1995a, 1997). *Rumex dentatus*, *Chenopodium album*, *Medicago sativa*, *Melilotus alba* and *Fumaria parviflora* are major broad-leaf weeds in rice-wheat cropping system (Singh *et al.* 1995b, Chhokar *et al.* 2006). *R. dentatus* is a major broad-leaf weed of *Rabi* season and is a serious problem of irrigated wheat particularly in rice-wheat cropping system in North-Western Indo-Gangetic alluvial plains of India comprising of the state of Haryana (Singh *et al.* 1995b).

Poor efficacy of metsulfuron-methyl against the toothed dock (*Rumex dentatus* L.) was observed under field conditions and the subsequent studies confirmed the instances of herbicide resistance in this weed (Chhokar *et al.* 2013, Chhokar 2014, Heap 2014, Singh 2016 and Singh *et al.* 2017). In addition to metsulfuron herbicides like carfentrazone, mesosulfuron + iodosulfuron and 2,4-D ester have also been recommended for use in wheat crop for the control of broad-leaf weeds including the *Rumex* spp. It is worth to study the efficacy of these herbicides as well against this weed for possible resistance. There is a need to understand the level of resistance in different populations from rice-wheat belt of Indo-Gangetic plains against different broad-leaf weed herbicides. In addition, there is also a need to evaluate alternate herbicidal options for its management so that the problem of herbicide resistance may be tackled effectively by appreciating all attending factors in the production package of wheat crop including the likely phytotoxicity to wheat crop at higher doses.

Experimental details

A pot experiment was carried out in CRD (completely randomized design) replicated thrice using seeds of four populations of *Rumex dentatus* named as HHH (HAU Hisar), UPH (Ujha, Panipat), JHH (Jind), collected from putative resistance affected farmer's fields and an unidentified *Rumex*. sp from farmers field in Jhajjar district of Haryana JJR (Jhajjar). Seeds collected from research farm, CCSHAU, Hisar were used as standard check for comparison. Three treatments (mesosulfuron + iodosulfuron, 2,4-D ester and carfentrazone) were taken and applied at three doses (0.5X, X and 2.0X) to evaluate herbicide resistance in *Rumex* spp. and for its management.

Pot preparation

Soil was taken from Agronomy Research Farm area for filling the pots, which was free from seeds of *Rumex* spp. and not exposed to herbicides for the last two years. The soil was air-dried, well crushed in fine particles to pass through a sieve of 2 mm pore size. Plastic pots (63 diameter) were filled with 2 kg material comprising sand, vermi-compost and field soil in ratio of 2:3:1. Before sowing, the pots were properly watered in order to maintain optimum soil moisture and to exhaust the soil in the pots from weed seed bank. Populations of *Rumex* spp. were sown on 27th December, 2017. Fifteen seeds of *Rumex* spp. were sown in each pot at a depth of 3-4 cm. The pots were watered immediately after sowing. After the emergence, thinning was done and 10 plants/pot were maintained for the application of POE herbicides. The plants were sprayed at 38 DAS on 4th February, 2018. Herbicides were sprayed with a knapsack sprayer fitted with flat fan nozzle delivering 300 l/ha spray volume at 40 psi pressure. Unsprayed check was maintained for comparison of results. Harvesting was done on 26th April, 2018 at 120 DAS.

Observations recorded on *Rumex* spp.

Plant height: The plant height (cm) was measured from soil surface to the tip of the fully opened leaf at spraying time, 2 and 4 weeks after treatment (WAT).

Electrical conductivity (EC): The values of EC were taken at 4 WAT. At first, individual weed samples were placed in flasks containing distilled water for one day. After this, flasks containing samples were boiled to specific temperature enabling the salt of samples to dissolve in distilled water. Then EC reading was taken.

Chlorophyll fluorescence: The value of Chlorophyll fluorescence (Fv/Fm) were taken at 7 DAT (days after treatment) with the help of Hansatech chlorophyll fluorescence meter. In chlorophyll fluorescence meter, clips were used for dark adaptation. At first, these clips are fitted on leaves for twenty minutes period. Then these clips are hooked on chlorophyll fluorescence meter to record the chlorophyll fluorescence of the leaves, where the clips were initially fitted.

Per cent control: Per cent control of *Rumex* spp. was recorded at 4 WAT. Rating was done in 0-100 scale (0 means no control and 100 means complete control of *Rumex* spp.). This data was observed by comparing each treatment with unsprayed control.

Dry weight of weeds: The weed samples present in pots were harvested at 120 DAS and these samples were first dried under the sun light and then kept in oven at 65±5^{0}C till a constant weight was achieved. The dried samples were weighed and dry weight was expressed as g/pot.

Statistical analysis: All the observations were statistically analysed by using software OP STAT. Angular transformation also known as Arcsine transformation was used in per cent control data of weeds. Formula used for angular transformation was:

Arcsine transformation = ARSIN [SQRT(germination/100)]x90/1.571

Carfentrazone dose-response studies

The data pertaining the effect of carfentrazone on the plant height, electrical conductivity and per cent control at 4 weeks after treatments (WAT), chlorophyll fluorescence at 7 days after treatment (DAT) and dry weight at harvesting of various *Rumex* populations is presented in **Table 1**. As per the mean data over carfentrazone doses, significantly higher plant height (23.8 cm) and higher chlorophyll fluorescence (0.74 Fv/Fm) was observed in UPH followed by JHH, HHH and JJH, respectively. As per the mean data over *Rumex* populations, half dose of carfentrazone resulted in 14.2% higher plant height and 17.7% higher plant chlorophyll fluorescence over recommended dose, whereas double dose resulted in 9.1% lower plant height and 14.5% lower plant chlorophyll fluorescence than recommended dose. Significantly lower EC (ds/m) was observed in UPH (0.13), followed by JHH (0.19), HHH (0.22) and JJH (0.28) at 4 WAT.

As per the mean mortality data (%) recorded at 4 WAT over herbicide doses, significantly lower mortality (%) was recorded in UPH (30) followed by JHH (38), JJH (40) and HHH (65).The per cent mortality observed in JHH was found statistically at par with JJH. Half dose of carfentrazone resulted in 14.3% lower mortality in comparison to the recommended dose, whereas double dose resulted in 22.4% higher mortality than recommended dose. As per the mean data over carfentrazone doses recorded at harvesting (120 DAS), significantly higher dry weight (g/pot) was recorded in UPH (2.20) followed by JHH (1.73), JJH (1.43) and HHH (0.96). Significant differences were observed in herbicide doses with respect to dry weight. Half dose of carfentrazone resulted in 24.4% higher dry weight over recommended dose, whereas double dose resulted in 32.5% lower dry weight than recommended dose over all populations.

Rumex populations except HHH were not controlled by carfentrazone even at double of the recommended dose. It provided 58, 72 and 62% mortality in UPH, JHH and JJR, respectively at double of the recommended dose which may not be rated as satisfactory in actual field condition. Chhokar *et al.* 2011 and Shalu 2019 also reported moderate efficacy of carfentrazone against *Chenopodium* spp. These results vary from the findings of Chhokar *et al.* (2007) and same could be attributed to the development of resistance in above referred populations. Wherever herbicide efficacy has been achieved at double of the recommended dose, its extrapolation at field level intervention has to be correlated with the selectivity index of wheat crop with respect to that particular herbicide. The herbicide efficacy at double of the recommended dose would cease to be of significance if it proves phytotoxic to wheat crop. A reduction in Fv/Fm value was observed in carfentrazone treated plants and this result is in the line with the finding of Kumar *et al.* 2008.

Table 1. Plant height, chlorophyll fluorescence, electrical conductivity, mortality percentage and dry weight of *Rumex* populations as influenced by carfentrazone application.

Populations	Carfentrazone (g/ha)				
	0	7.2	14.4	28.8	Mean
Plant height (cm) at 4 WAT					
HHH	26.3	22.0	19.0	16.3	20.9
UPH	27.3	25.0	22.0	20.7	23.8
JHH	27.7	23.0	20.7	18.3	22.4
JJH	21.7	20.0	17.0	16.3	18.8
Mean	25.8	22.5	19.7	17.9	
	LSD (p=0.05)			SEm	
Population	0.9			0.32	
Herbicide	0.9			0.32	
Population x herbicide	NS			0.63	
Chlorophyll fluorescence (Fv/Fm) at 7 DAT					
HHH	0.85	0.70	0.51	0.35	0.60
UPH	0.91	0.77	0.69	0.61	0.74
JHH	0.91	0.72	0.64	0.55	0.70
JJH	0.84	0.70	0.67	0.62	0.71
Mean	0.88	0.73	0.62	0.53	
	LSD (p=0.05)			SEm	
Population	0.02			0.005	
Herbicide	0.02			0.005	
Population x herbicide	0.03			0.010	
Electrical conductivity (Ds/m) at 4 WAT					
HHH	0.02	0.28	0.37	0.46	0.8
UPH	0.03	0.09	0.15	0.26	0.13
JHH	0.03	0.13	0.20	0.39	0.19
JJH	0.03	0.25	0.28	0.31	0.22
Mean	0.03	0.19	0.25	0.36	
	LSD (p=0.05)			SEm	
Population	0.02			0.005	
Herbicide	0.02			0.005	
Population x herbicide	0.03			0.011	
Mortality percentage at 4 WAT					
HHH	0(0)	61(77)	69(87)	81(97)	53(65)
UPH	0(0)	30(25)	37(37)	50(58)	29(30)
JHH	0(0)	35(33)	43(47)	58(72)	34(38)
JJH	0(0)	41(43)	47(53)	52(62)	35(40)
Mean	0(0)	42(45)	49(56)	60(72)	
	LSD (p=0.05)			SEm	
Population	2			0.8	
Herbicide	2			0.8	
Population x herbicide	5			1.5	
Dry weight (g/pot) at harvesting					
HHH	2.47	0.70	0.53	0.13	0.96
UPH	3.23	2.30	1.97	1.30	2.20
JHH	2.83	1.80	1.37	0.93	1.73
JJH	2.40	1.33	1.07	0.93	1.43
Mean	2.73	1.53	1.23	0.83	
	LSD (p=0.05)			SEm	
Population	0.14			0.05	
Herbicide	0.14			0.05	
Population x herbicide	0.27			0.10	

Original figures in parentheses were subjected to angular transformation. WAT, weeks after treatment; DAT, days after treatment. DAS- days after sowing

Mesosulfuron + iodosulfuron dose-response studies

As per the mean data on plant height recorded over mesosulfuron + iodosulfuron doses at 4 WAT, significantly higher plant height (23.9 cm) was observed in UPH which was statistically at par with JHH (23.2 cm) but significantly higher than other populations (**Table 2**). Similarly higher chlorophyll fluorescence was observed in UPH and JHH, followed by JJH and HHH. Half dose of mesosulfuron + iodosulfuron resulted in 12.1% higher plant height and 6.88% higher plant chlorophyll fluorescence over recommended dose, whereas reverse trend was observed in case of double dose. The double dose resulted in 8.6% lower plant height and 6.8% lower plant chlorophyll fluorescence than recommended dose. Significantly lower EC (ds/m) was observed in UPH and JHH (0.06) followed by HHH (0.26) and JJH (0.20).

As recorded at 4 WAT, significantly lower mortality (%) was recorded in UPH (8) followed by JHH (18), JJH (53) and HHH (54). When compared the mortality achieved at recommended dose (X), the half dose of mesosulfuron + iodosulfuron resulted in 10% lower mortality, whereas double dose resulted in 17.5% higher mortality. When data was averaged over mesosulfuron + iodosulfuron doses, significantly higher dry weight (g/pot) was recorded in UPH (2.83) followed by JHH (2.27), HHH (1.18) and JJH (1.06). Mean dry weight in JJH was found statistically at par with HHH. No significant interaction was observed between herbicide doses and *Rumex* populations with respect to dry weight. Mesosulfuron + iodosulfuron 7.2 and 14.4 g/ha resulted statistically similar dry weight among all populations at harvesting (120 DAS). Half dose of mesosulfuron + iodosulfuron resulted in 9% higher dry weight over recommended dose, whereas double dose resulted in 12.9% lower dry weight than recommended dose over all populations.

All the *Rumex* populations showed unsatisfactory control even at double of the recommended dose of mesosulfuron + iodosulfuron. However, degree and extent of resistance showed variation across the populations. The highest dose (2X) provided only 17% and 28% mortality in UPH and JHH, respectively, whereas the corresponding figures for JJH and HHH was 82%. This may be due to resistance to mesosulfuron + iodosulfuron in UPH and JHH. Singh *et al.* (2016, 2017) and Bhullar *et al.* (2012) also observed the low efficacy of metsulfuron based herbicides against broad-leaf weeds of wheat. But these results vary with finding of Kaur *et al.* 2017 and Chhokar *et al.* 2007 that may be due to the development of resistance in the referred populations. UPH population attained higher plant height, chlorophyll fluorescence, fresh and dry weight and lowest EC which again is the manifestation of resistance behaviour in weeds. The results indicate that mesosulfuron + iodosulfuron may have to withdraw from the field level management practices recommended for *Rumex* though such advisory may be area specific.

Table 2. Plant height, chlorophyll fluorescence, electrical conductivity, mortality percentage and dry weight of *Rumex* populations as influenced by mesosulfuron + iodosulfuron application

Populations	Mesosulfuron + iodosulfuron (g/ha)				
	0	7.2	14.4	28.8	Mean
Plant height (cm) at 4 WAT					
HHH	26.3	20.0	18.7	17.0	20.5
UPH	27.3	25.7	22.3	20.3	23.9
JHH	27.7	24.7	21.7	18.7	23.2
JJH	21.7	18.3	16.3	16.3	18.2
Mean	25.8	22.2	19.8	18.1	
	LSD (p=0.05)			SEm	
Population	1.2			0.41	
Herbicide	1.2			0.41	
Population x herbicide	NS			0.81	
Chlorophyll fluorescence (Fv/Fm) at 7 DAT					
HHH	0.85	0.73	0.62	0.56	0.69
UPH	0.91	0.86	0.84	0.80	0.85
JHH	0.91	0.84	0.82	0.78	0.84
JJH	0.84	0.71	0.66	0.63	0.71
Mean	0.88	0.79	0.74	0.69	
	LSD (p=0.05)			SEm	
Population	0.02			0.005	
Herbicide	0.02			0.005	
Population x herbicide	0.03			0.01	
Electrical conductivity (Ds/m) at 4 WAT					
HHH	0.02	0.24	0.37	0.40	0.26
UPH	0.03	0.05	0.07	0.09	0.06
JHH	0.03	0.05	0.07	0.09	0.06
JJH	0.03	0.22	0.25	0.29	0.20
Mean	0.03	0.14	0.19	0.22	
	LSD (p=0.05)			SEm	
Population	0.02			0.005	
Herbicide	0.02			0.005	
Population x herbicide	0.03			0.010	
Mortality percentage at 4 WAT					
HHH	0(0)	54(65)	57(70)	65(82)	44(54)
UPH	0(0)	12(7)	18(10)	24(17)	14(8)
JHH	0(0)	27(20)	29(23)	32(28)	22(18)
JJH	0(0)	51(60)	57(70)	65(82)	43(53)
Mean	0(0)	36(38)	40(43)	47(52)	
	LSD (p=0.05)			SEm	
Population	3			1.1	
Herbicide	3			1.1	
Population x herbicide	6			2.2	
Dry weight (g/pot) at harvesting					
HHH	2.47	0.97	0.80	0.47	1.18
UPH	3.23	2.83	2.73	2.50	2.83
JHH	2.83	2.23	2.07	1.93	2.27
JJH	2.40	0.73	0.60	0.50	1.06
Mean	2.73	1.69	1.55	1.35	
	LSD (p=0.05)			SEm	
Population	0.14			0.05	
Herbicide	0.14			0.05	
Population x herbicide	0.29			0.10	

Original figures in parentheses were subjected to angular transformation. WAT, weeks after treatment; DAT, days after treatment.

2,4-D ester dose-response studies

When data was averaged over 2,4-D ester doses, highest plant height (cm) was recorded in UPH (22.8) which was statistically at par with JHH (22.1) but significantly higher than other populations (**Table 3**). Highest plant chlorophyll fluorescence (Fv/Fm) as recorded at 7 DAT was observed in UPH (0.72) followed by JHH (0.71), HHH (0.64) and JJH (0.61). Mean plant chlorophyll fluorescence of UPH was found statistically at par with JHH. When compared with recommended dose (X), half dose of 2,4-D ester resulted in 9% higher plant height and 10.2% higher plant chlorophyll fluorescence, whereas double dose resulted in 7.4% lower plant height and 6.8% lower plant chlorophyll fluorescence.Significantly lower EC (ds/m) was observed in UPH (0.29) followed by JHH (0.30) and JJH (0.33) and HHH (0.34).

In the mean data over herbicide doses as recorded at 4 WAT, significantly lower mortality (%) was observed in UPH (58) followed by JHH (61), HHH (69) and JJH (71).When compared with recommended dose (X), half dose of 2,4-D ester resulted in 18.1% lower mortality, whereas double dose resulted in 22.2% higher mortality. When data was averaged over 2,4-D ester doses, significantly higher dry weight (g/pot) was recorded in UPH (1.30) followed by JHH (1.18), JJH (0.87) and HHH (0.87). Half dose of 2,4-D ester resulted in 64% higher dry weight than recommended dose, whereas double dose resulted in 68% lower dry weight than recommended dose over all populations.

All populations were found sensitive to 2,4-D ester at recommended and 2X rate, though effect was lower on UPH population. Singh *et al.* (2017) and Chhokar *et al.* (2007 and 2017) also reported good efficacy of 2,4-D ester against broad-leaf weed of wheat, but these results are not in accordance with the findings of Chhokar *et al.* (2015) due to resistant behaviour of particular populations. The results indicate the efficacy of 2,4-D ester as the field level management practices for the resistant populations of *Rumex*. Reduction in chlorophyll fluorescence value was observed in 2,4-D ester treated plants and this is in the harmony with the finding of Singh and Singh (2006 and 2007).

It may be concluded that by knowing germination percentage of populations (highest in UPH population), seed formation of *Rumex* spp. can be arrested, which reduces the carry over weed infestation in the next season and it could be used as a tool in resistance management in this weed. Singh and Punia (2008) reported that *Rumex spinosus* was sensitive to flooding duration but not *R. dentatus*; whereas reverse was true for seeding depths. These agronomic practices including herbicide mixtures and sequential applications (Singh 2015) can be employed for the management of *Rumex* populations where possible. Majority of populations showed resistance against mesosulfuron + iodosulfuron even at double of the recommended dose. The resistance against the above mentioned herbicide was also reflected in terms of comparatively higher plant height, chlorophyll fluorescence and dry weight and lowest EC in the resistant populations, thus confirming the poor efficacy of mesosulfuron + iodosulfuron. All the populations except HHH showed poor efficacy against carfentrazone even at double of the recommended dose. *Rumex* populations on a whole

Table 3. Plant height, chlorophyll fluorescence, electrical conductivity, mortality percentage and dry weight of *Rumex* populations as influenced by 2,4-D ester application

Populations	2,4-D ester (g/ha)				
	0	7.2	14.4	28.8	Mean
Plant height (cm) at 4 WAT					
HHH	26.3	19.3	17.3	16.0	19.8
UPH	27.3	23.0	21.3	19.3	22.8
JHH	27.7	22.3	20.0	18.3	22.1
JJH	21.7	17.3	16.7	16.0	17.9
Mean	25.8	20.5	18.8	17.4	
	LSD (p=0.05)			SEm	
Population	0.8			0.28	
Herbicide	0.8			0.28	
Population x herbicide	1.6			0.56	
Chlorophyll fluorescence (Fv/Fm) at 7 DAT					
HHH	0.85	0.65	0.58	0.49	0.64
UPH	0.91	0.71	0.65	0.61	0.72
JHH	0.91	0.70	0.63	0.60	0.71
JJH	0.84	0.54	0.53	0.50	0.61
Mean	0.88	0.65	0.59	0.55	
	LSD (p=0.05)			SEm	
Population	0.02			0.007	
Herbicide	0.02			0.007	
Population x herbicide	0.04			0.013	
Electrical conductivity (Ds/m) at 4 WAT					
HHH	0.02	0.35	0.45	0.55	0.34
UPH	0.03	0.30	0.39	0.46	0.29
JHH	0.03	0.31	0.39	0.48	0.30
JJH	0.03	0.41	0.42	0.47	0.33
Mean	0.03	0.34	0.41	0.49	
	LSD (p=0.05)			SEm	
Population	0.01			0.004	
Herbicide	0.01			0.004	
Population x herbicide	0.02			0.007	
Mortality percentage at 4 WAT					
HHH	0(0)	67(85)	72(90)	89(100)	57(69)
UPH	0(0)	49(57)	61(77)	85(98)	49(58)
JHH	0(0)	52(62)	65(82)	89(100)	52(61)
JJH	0(0)	66(83)	89(100)	89(100)	61(71)
Mean	0(0)	59(72)	72(87)	88(100)	
	LSD (p=0.05)			SEm	
Population	2			0.82	
Herbicide	2			0.82	
Population x herbicide	5			1.6	
Dry weight (g/pot) at harvesting					
HHH	2.47	0.53	0.33	0.13	0.87
UPH	3.23	1.07	0.77	0.13	1.30
JHH	2.83	1.10	0.63	0.13	1.18
JJH	2.40	0.57	0.27	0.23	0.87
Mean	2.73	0.82	0.50	0.16	
	LSD (p=0.05)			SEm	
Population	0.12			0.04	
Herbicide	0.12			0.04	
Population x herbicide	0.24			0.08	

Original figures in parentheses were subjected to angular transformation. WAT, weeks after treatment; DAT, days after treatment were found sensitive to 2,4-D ester, as it provided significant visual mortality in case of all populations at recommended doses. The satisfactory control of 2,4-D ester to majority of populations provides an opportunity to integrate this herbicide in weed management options at field level.

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Indian Journal of Weed Science **53**(2): 188–190, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of tillage and pre-mix application of herbicides on weed growth and productivity of late-sown wheat

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Article information

DOI: 10.5958/0974-8164.2021.00035.6

Type of article: Research note

Received : 2 January 2021
Revised : 9 June 2021
Accepted : 12 June 2021

Key words

Clodinafop + metsulfuron-methyl

Pre-mix

Sulfosulfuron + metsulfuron methyl

Wheat

Zero tillage

ABSTRACT

A field experiment was conducted during the *Rabi* (winter) season of 2016-17 at Agricultural Farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal to study the effect of tillage and weed management on weed growth, productivity and profitability of wheat. The experiment was laid out in a split-plot design with three replications comprising of two tillage and six weed management practices in main and sub plots, respectively. Results showed that zero tillage registered significantly lower density of grasses and total weeds as compared to conventional tillage. Among the weed management practices, weed free plot registered significantly higher grain yield (3.6 t/ha), which was statistically at par with the application of both the doses (25 and 35 g/ha) of sulfosulfuron ethyl + metsulfuron-methyl and clodinafop-propargyl + metsulfuron-methyl 96 g/ha. Zero tillage with the application of sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha fetched the highest net return (₹ 40,119/ha) and return per rupee invested (2.3), which was comparable with sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 25 g/ha. Thus, in late sown wheat, zero tillage along with pre-mix application of sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 25-35 g/ha and clodinafop-propargyl + metsulfuron-methyl 96 g/ha at 30 DAS appeared to be promising for effective weed control and higher productivity as well as profitability.

Wheat (*Triticum aestivum*) is the second most important crop in India whereas in West Bengal, its share of total cultivated land is very limited. Total area and production of wheat during 2017-18 has been reported to be 29.58 million ha and 99.70 million tonnes, respectively with a productivity of 3.3 t/ha in India (DAC&FW, 2018). Zero tillage is becoming popular because of its suitability in rice-wheat cropping system. Diversified weed flora causes severe yield loss in wheat. Pre-mixed broad-spectrum herbicide is cost-effective against complex weed flora. Hence, the present experiment was conducted to study the effect of tillage and weed management on weed growth, productivity and profitability of late sown wheat in the sub-humid red and lateritic agro-ecological zone of the tropics using different doses of premix herbicide *i.e.* sulfosulfuron-ethyl + metsulfuron-methyl and clodinafop-propargyl + metsulfuron-methyl.

The field experiment was conducted during *Rabi* (winter) season of 2016-17 in the Agricultural Farm of Institute of Agriculture, Visva-Bharati, Sriniketan (located at $23^0$40.105′ N latitude and $87^0$39.521′ E longitude at an altitude of 56 m above the mean sea level), West Bengal, which is situated in the sub-humid red and lateritic agro-ecological zone of the tropics. The soil was sandy loam in texture, slightly acidic in reaction (p^H 5.8) and low in organic carbon (0.42%), available nitrogen (133.4 kg/ha) and extractable potassium (123.7 kg/ha) whereas, medium in available phosphorous (11.5 kg/ha).

Two tillage practices, *viz.* zero tillage (ZT) and conventional tillage (CT) in main plot and six weed management practices, *viz.* sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 25 g/ha, sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha, clodinafop-propargyl 15% + metsulfuron-methyl 1% WP 80 g/ha, clodinafop-propargyl 15% + metsulfuron-methyl 1% WP 96 g/ha, weed free (two hand weeding at 25 and 40 DAS) and weedy check in sub plot, were evaluated in a split plot design with three replications. The wheat variety *'HD 2824 (Poorva)'* was sown on

11th December 2016 with a seed rate of 120 kg/ha for both zero and conventional tilled plots. Sowing was done mechanically with the help of national zero till ferti-cum-seed drill machine by maintaining a row to row spacing of 20 cm. The recommended package of practices was imposed uniformly during the course of experiment to all the treatments. The herbicides were sprayed using battery operated knapsack sprayer fitted with a flat fan nozzle at a spray volume of 500 L of water per hectare at 30 days after sowing. Density and biomass of different weeds were taken by placing the quadrat of 50 × 50 cm randomly in the sampling area. Urea and complex fertilizer (10-26-26) were the sources of nutrients applied at a recommended dose of 120:60:60 N, P and K kg/ha, respectively. Half amount of nitrogen, full dose of phosphorus and potassium was applied at the time of sowing and remaining nitrogen was applied through urea in two equal splits at crown root initiation (CRI) stage and booting stage. The field was kept moist throughout the crop growing season by giving surface irrigation. One pre sowing irrigation was given before the wheat seeding for uniform germination. Total number of irrigations including pre sowing irrigation was six, whereas the rest five irrigations were applied at CRI, tillering, late jointing, flowering and dough stages of crop growth.

The data recorded from the experiment were subjected to the analysis of variance (ANOVA) as applied to split-plot design. The significance of different sources of variation was tested with the help of 'F' test at the 5% level of significance. Data showing wide variation and having the value zero in weed density and biomass, were subjected to square root transformation [$\sqrt{x+0.5}$] before statistical analysis.

Effect on weeds

Digitaria sanguinalis with 13.2% relative density (RD), *Echinochloa colona* (2.6% RD) among the grasses and *Polygonum plebeium* (63.0% RD), *Gnaphalium indicum* (12.5% RD), and *Spilanthes calva* (8.7% RD) among the broad-leaved were the predominant weeds found in the experimental field. In weedy check, the broad-leaved weeds comprised of 84.2% density and 69.5% biomass, whereas those of grassy weed was 15.8 and 30.5% of total weed, respectively (**Table 1**).

Zero tillage registered significantly lower density of grassy and total weeds (27 and 17%, respectively) as compared to conventional tillage. Crust formation in absence of tillage in zero tilled plot, may be the main reason behind the reduction in emergence of grassy weeds. However, the biomass of grassy, broad-leaved and total weeds did not vary significantly between tillage practices. Among the weed management practices, sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha recorded significantly the lowest density and biomass of grassy, broad-leaved and total weeds and was found at par with sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 25 g/ha except grassy weed density. Ready mixed application of sulfosulfuron + metsulfuron executed an excellent control of both *D. sanguinalis* and *P. plebeium*, which were found predominant in weedy check plot. Application of clodinafop-propargyl 15% + metsulfuron-methyl 1% WP 96 g/ha was also statistically at par with sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha with respect to density and biomass of broad-leaved weed. This could be explained by the evidence that better control of *P. plebeium* and *G. indicum* was obtained due to the presence of metsulfuron in ready mix product. Similar results were obtained from Tiwari *et al.* (2016) and Meena *et al.* (2019).

Effect on crop

The number of grains/spike, test weight, no. of spikes/m^2, grain and straw yield and harvest index of wheat didn't vary between tillage practices (**Table 2**). But those varied significantly among the weed management practices except test weight. This result

Table 1. Effect of tillage and weed management on density and biomass of weeds in wheat

Treatment	Weed density (no/m^2) at 45 DAS			Weed biomass (g/m^2) at 45 DAS		
	Grassy	BLW	Total	Grassy	BLW	Total
Tillage practice						
Zero tillage	3.55 (12.09)	9.77 (94.88)	10.37 (106.97)	1.71 (2.41)	2.63 (6.42)	3.05 (8.79)
Conventional tillage	4.13 (16.59)	10.62 (112.26)	11.39 (129.17)	1.86 (2.96)	2.69 (6.74)	3.19 (9.68)
LSD (p=0.05)	0.51	NS	0.94	NS	NS	NS
Weed management practice						
Sulfosulfuron-ethyl + MSM 25 g/ha	2.99 (8.42)	10.84 (117.09)	11.23 (125.64)	0.90 (0.32)	2.22 (4.41)	2.29 (4.73)
Sulfosulfuron-ethyl + MSM 35 g/ha	2.34 (4.98)	9.68 (93.20)	9.94 (98.40)	0.87 (0.25)	2.09 (3.87)	2.15 (4.14)
Clodinafop-propargyl + MSM 80 g/ha	4.97 (24.15)	11.39 (129.26)	12.42 (153.69)	2.43 (5.42)	2.71 (6.86)	3.60 (12.43)
Clodinafop-propargyl + MSM 96 g/ha	4.46 (19.42)	11.10 (122.74)	11.96 (142.61)	1.90 (3.12)	2.44 (5.43)	3.01 (8.55)
Weed free (hand weeding at 25 and 40 DAS)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Weedy check	7.59 (57.05)	17.43 (303.37)	19.00 (360.49)	3.89 (14.65)	5.81 (33.24)	6.96 (47.97)
LSD (p=0.05)	0.57	1.54	1.53	0.30	0.41	0.42
Interaction	S	S	S	S	S	S

*Figures within parentheses indicate original values and the data were transformed to $\sqrt{x+0.5}$ before analysis; MSM = Metsulfuron-methyl

Table 2. Effect of tillage and weed management on yield component, yield and economics of wheat

Treatment	No. of grains/ spike	Test weight (g)	No. of spikes/ m^2	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Cost of cultivation (`/ha)	Gross return (`/ha)	Net returns (`/ha)	Returns/ rupee invested
Tillage practice										
Zero tillage	42.3	41.0	257	3.3	4.6	41.0	33725	67039	33314	2.0
Conventional tillage	40.6	40.9	250	3.1	4.5	40.7	43765	64581	20816	1.5
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	-	NS	4918	0.1
Weed management practice										
Sulfosulfuron-ethyl + MSM 25g/ha	42.3	41.7	253	3.3	4.6	41.9	36023	68182	32159	1.9
Sulfosulfuron-ethyl + MSM 35 g/ha	44.4	41.8	278	3.5	4.8	42.2	36249	71486	35237	2.0
Clodinafop-propargyl + MSM 80 g/ha	41.9	40.1	242	3.1	4.4	41.4	37026	64086	27060	1.8
Clodinafop-propargyl + MSM 96 g/ha	43.7	41.9	260	3.3	4.8	41.1	37542	68378	30836	1.9
Weed free (hand weeding at 25 and 40 DAS)	41.2	41.2	285	3.6	4.9	42.8	50815	73571	22756	1.5
Weedy check	35.1	39.4	204	2.3	4.1	35.4	34815	49156	14341	1.4
LSD (p=0.05)	5.5	NS	30	0.4	0.5	2.5	-	5140	5140	0.2
Interaction	S	NS	S	S	S	S	-	S	S	S

MSM = Metsulfuron-methyl

were in agreement with Jat *et al.* (2013). Weed free plot registered significantly the highest grain yield (3.6 t/ha), straw yield (4.9 t/ha) and harvest index (42.8%), which was statistically on par with the application of sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha, sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 25 g/ha and clodinafop-propargyl 15% + metsulfuron-methyl 1% WP 96 g/ha. While, weedy check registered significantly the lowest number of grains/ear (35.1), no. of ears/m^2 (204), grain yield (2.3 t/ha), straw yield (4.1 t/ha) and harvest index (35.4%). Consistent with our findings, application of metsulfuron + clodinafop herbicide in zero tilled wheat resulted in higher grain and straw yields (Singh *et al.* 2017). The weed infestation in the weedy check, took away the resources like water, nutrient, space, sunlight *etc*. Hence under stress, the crop plants could not achieve its optimum growth and development, which ultimately reduced the yield attributes and yield of wheat. These results were in conformity with those of Meena *et al.* (2019).

Effect on economics

Zero tillage incurred the lowest cost of cultivation (₹ 33,725/ha) and fetched the highest gross return (₹ 67,039/ha) as compared to conventional tillage (cost of cultivation and gross return are ₹ 43,765 and 64,521/ ha, respectively). Among weed management practices, the highest cost of cultivation was incurred in weed free check. Net return and return per rupee invested from wheat cultivation were significantly influenced by tillage and weed management practices (**Table2**). Zero tillage registered the highest net return (₹ 33,314/ha) and return per rupee invested (2.0). Similar results were also obtained by Kumar *et al.* (2013). Irrespective of tillage practices, sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha, fetched the highest net return (₹ 35,237/ha) and return per rupee invested (2.0) and remained at par with sulfosulfuron ethyl 75% + metsulfuron-methyl 5% WG 25 g/ha and clodinafop-propargyl 15% + metsulfuron-methyl 1% WP 96 g/ha. Interaction amongst tillage and weed management practices revealed that zero tillage with the application of sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha fetched the highest net return (₹ 40,119/ ha) and return per rupee invested (2.3) in wheat.

Thus, it may be concluded that in late sown wheat, zero tillage along with pre-mix application of either sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG25-35 g/ha or clodinafop-propargyl 15% + metsulfuron-methyl 1% WP 96 g/ha at 30 DAS provided effective weed management and registered higher productivity as well as profitability in lateritic soil of West Bengal.

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Indian Journal of Weed Science 53(2): 191–194, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of sowing dates and weed control treatments on weed management and grain yield of greengram under rainfed condition

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Article information

DOI: 10.5958/0974-8164.2021.00036.8

Type of article: Research note

Received : 7 May 2021

Revised : 16 June 2021

Accepted : 19 June 2021

Key words

Greengram

Growth

Herbicides

Seeding dates

Weed control

Yield

ABSTRACT

The field experiment was conducted during 2014-16 in *Rabi* (winter) season (October - December) at Agricultural Research station, Kovilpatti, Tamil Nadu, India. The treatment combinations comprised of three dates of seeding, *viz*. last week of September, 2nd week of October and last week of October in main plot with four weed management treatments, *viz*. pendimethalin 0.75 kg/ha pre-emergence application (PE) *fb* hand weeding (HW) on 20 days after seeding (DAS), pendimethalin 0.75 kg/ha PE *fb* quizalofop-ethyl 50 g/ha post-emergence application (PoE) on 20 DAS, pendimethalin 0.75 kg/ha PE *fb* imazethapyr 50 g/ha PoE on 20 DAS, imazethapyr 50 g/ha + quizalofop-ethyl 50 g/ha (tank mix) PoE at 20 DAS in the sub plot. The seeding during last week of September registered increased growth and yield parameters, *viz*. dry matter production (DMP), leaf area index (LAI), number of pods/plants, pod length, number of seeds/pods which reflected on increased grain yield (850 kg/ha). Among the weed management treatments, pendimethalin 0.75 kg/ha PE *fb* HW on 20 DAS recorded significantly lower weed density and weed biomass which in turn produced increased growth and yield attributes and yield of the crop which was followed by application of pendimethalin 0.75 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE on 20 DAS.

Greengram is one of the major pulse crops of our country and also it serves as an important protein source of our Indian diet. Greengram gives low seed yield mainly due to poor management and low soil fertility. In Tamil Nadu, blackgram (46%) and greengram (25%) are the major pulse crops accounting for about 71% of the area under pulses and the average yield level is far below the national average (650 kg/ha). The productivity of greengram during 2001-2016 ranged from 227 kg/ha to 788 kg/ha and the mean value of productivity of greengram was 450 kg/ha (Vasanthakumar 2016). This indicates that there is a wide scope for increasing the productivity of greengram by proper management practice. Weed infestation is one of the major constraints in greengram cultivation. Competition with the weeds leads to 30 to 80% reduction in grain yield of greengram during summer and *Kharif* (rainy) seasons while 70-80% during *Rabi* (winter) season. (Algotar *et al*. 2015). The pendimethalin (pre-emergence) 1000 g/ha + one hand weeding (Singh *et al*. 2015); pendimethalin 30 EC + imazethapyr 2 EC) 1.00 kg/ha (Tamang *et al*. 2015), hand weeding at 20 and 30 DAS and hand hoeing at 20 and 30 DAS (Chaudhari *et al*. 2016) were found to be most effective in reducing density and biomass of weeds and producing maximum yield of greengram in different states of India. The relative efficiency of different herbicide when applied alone or in combination with other herbicides and management practices should be known to select location specific best weed control methods. Hence, the present study was under taken to study the effect of different weed management practices on weed control and grain yield of greengram under different weather conditions prevailing at different dates of seeding in Kovilpatti, Tamil Nadu.

The field experiment was conducted during 2014-16 in *Rabi* season (October - December) at Agricultural Research Station, Kovilpatti, Tamil Nadu, India. The experiment was conducted in split-plot design with three replications. The treatments comprised of three dates of sowing, *viz*. last week of September, 2nd week of October and last week of October as on 24.09.2015, 08.10.2015 and 22.10.2015, respectively in main plot with four different weed management practices, *viz*. pendimethalin at 0.75 kg/ha pre-emergence application (PE) *fb* hand weeding (HW) at 20 days after seeding (DAS), pendimethalin at 0.75 kg/ha PE *fb* quizalofop-ethyl at 50 g/ha post-emergence application (PoE) on 20 DAS, pendimethalin at 0.75 kg/ha PE *fb* imazethapyr at 50 g/ha PoE on 20 DAS, imazethapyr at 50 g/ha + quizalofop-ethyl at 50 g/ha (tank mix) PoE on 20 DAS in the sub-plot. The soil is clay in texture with sub angular blocky in structure with WHC of 65%, EC: 0.32/dSm, pH: 8.45, available N: 140 kg/ha, available P: 15.5 kg/ha and available K: 340 kg/ha. Application of fertilizers 12.5: 25: 12.5 + 10 kg NPK+S/ha was done in the form of urea, DAP and MOP with the spacing of 30 × 10 cm. Irrigation was not given since the crop was grown as rainfed and sufficient rainfall occurred during the growing season. Data on plant height, leaf area index (LAI), dry matter production (DMP), number of pods/ plants, number of seeds/pods, test weight and seed yield were recorded replication wise and were statistically analysed. The weed flora at 20 DAS, weed density, relative weed density and biomass at 20 and 40 DAS were recorded. The meteorological data regarding rainfall, temperature, relative humidity and sunshine hours were collected from meteorological observatory located nearby experimental field at Agricultural Research Station, Kovilpatti. Derived parameters like Accumulated Growing Degree Day (AGDD) and Accumulated Helio Thermal Unit (AHTU) were worked out.

Rainfall, AGDD and AHTU Vs time of sowing

Among different sowing windows, the crop sown during the last week of September (24.09.2015) received higher amount of AGDD (1389) and AHTU (6452) and also higher amount of rainfall during the vegetative stage of the crop (**Table 1**). Sowing of greengram during 22.10.2015 (last week of October) received lesser amount of AGDD (1297) and AHTU (5570) and also less rainfall at vegetative (73.8 mm) and pod initiation (1.0 mm) stages and higher amount of rainfall (66.4 mm) during 50% flowering stage affected the crop very severely which was reflected by poor yield attributes and yield of greengram. This finding closely resembles to those reported by Miah *et al.* (2009) who opined that, the highest seed yield obtained from early sowing (2[nd] March) might be due to suitable temperature prevailing accompanied by higher soil moisture content due to sufficient rainfall in April, which enhanced the vegetative as well as reproductive growth of the crop. Meanwhile the lowest yield was recorded by late sown crop (April) due to excessive rainfall during pod filling stage in the month of June.

Weed flora, weed density and biomass

The broad-leaved weeds, *viz. Abutilon hirtum, Acalypha indica, Amaranthus viridis, Ageratum conyzoides, Corchorus olitorius, Celosia argentea, Digeria muricata, Euphorbia hirta, Phyllanthus maderaspatensis, Trianthema portulacastrum, Tridax procumbens* and sedge *Cyperus rotundus* and grassy weeds: *Cynodon dactylon, Rottboellia cochin-chinensis* were observed in the experimental field and the relative density of different kinds of weeds is presented in **Table 3**.Variation in weed flora was noticed in different dates of sowing at 20 DAS. Broad-leaved weeds were higher in seeding prior to first monsoon rain (last week of September) (19 in number) whereas sedges were higher in greengram sown on last week of October (11.5). The grassy weeds remained same at different dates of sowing (**Table 2**). Among the different kinds of weeds observed in the experimental field, among the broad-leaved weeds *Digeria muricata*, and *Trianthema portulacastrum*; in sedges *Cyperus rotundus* and in grasses *Rottboellia cochinchinensis* recorded higher relative weed density nearly 25% each than other weed species (**Table 3**).

Among the weed management practices, application of pendimethalin 0.75 kg/ha PE *fb* HW on 20 DAS recorded significantly lower weed density (30.0 and 24.4 in number) and biomass (130.4 and 166.4 kg/ha) during 20 and 40 DAS, respectively which in turn influences increased growth and yield attributes and yield of the crop which was followed

Table 1. Rainfall, Accumulated Growing Degree Day (AGDD) and Accumulated Helio Thermal Unit (AHTU) received (mm) during different phenological stages of greengram

Phenological stages	Rainfall			AGDD			AHTU		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
Germination	21.8	21.8	16.6	60	61	44	240	435	92
Vegetative	142.4	142.4	73.8	538	511	501	2792	2335	2675
50% flowering	35.6	35.6	66.4	125	129	124	844	868	80
50 % pod initiation	14.6	14.6	1.0	71	71	61	143	490	43
Pod development	79.6	79.6	39.8	503	470	445	1938	1330	1821
Physiological maturity	1.2	1.2	16.4	90	97	122	494	395	859
Total	295.2	295.2	214.0	1387	1339	1297	6452	5853	5570

D_1: Last week of September; D_2: Second week of October; D_3: Last week of October by pendimethalin 0.75 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE (**Table 2**). Similar observations were made earlier by Singh *et al*. (2015). Among total weed density at 20 and 40 DAS and weed biomass at 20 DAS did not differ significantly due to dates of sowing as also reported by Meena *et al*. (2017)

Growth and yield parameters

The sowing during last week of September registered significantly higher plant height (65.2 cm), DMP (4556 kg/ha), no. of pods/plant (26.1), no. of seeds/pod (7.9), 100 seed weight (3.6 g) which might be due to well distributed high rainfall, AGDD and AHTU (**Table 1**) than later dates of sowing that enhanced photosynthetic accumulates (**Table 4**). Gurjar *et al*. (2018) also reported the advantage of earlier sowing over late sowing. Greengram sown on later dates experienced high temperature during growth stages, heat and moisture stress at anthesis stage and shortening of grain filling duration which resulted in quick desiccation of leaves, unbalanced ratio of photosynthesis and respiration which ultimately resulted in low dry matter accumulation (Meena *et al*. 2017), decreased weight per grain and reduce grain weight (Poudel *et al*. 2020).

Among the weed management practices, application of PE pendimethalin 0.75 kg/ha *fb* HW on 20 DAS recorded significantly lower weed density and weed dry weight which in turn produced increased growth and yield attributes, *viz*. plant height (64.2 cm), DMP (4425 kg/ha), no. of pods/plant (26.1), No. of seeds/pod (7.8), 100 seed weight (3.6

Table 2. Effect of dates of sowing and weed management treatments on weed density and weed biomass on 20 and 40 DAS

Treatment	Weed density (no./m^2)								Weed biomass (kg/ha)							
	20 DAS				40 DAS				20 DAS				40 DAS			
	BLW	Sedges	Grasses	Total weeds	BLW	Sedges	Grasses	Total weeds	BLW	Sedges	Grasses	Total weeds	BLW	Sedges	Grasses	Total weeds
Last week of September	4.3 (19.0)	2.5 (7.0)	3.0 (9.0)	5.9 (35.0)	5.6 (32.3)	2.9 (9.5)	2.1 (4.5)	6.8 (46.3)	5.7 (33.7)	4.6 (26.7)	8.5 (72.0)	11.5 (132.3)	14.0 (198.5)	5.2 (38.7)	5.9 (36.0)	16.5 (273.2)
Second week of October	4.0 (16.7)	2.5 (6.7)	2.6 (7.0)	5.5 (30.3)	5.1 (27.0)	2.3 (7.3)	1.8 (3.5)	6.0 (37.8)	7.3 (54.3)	4.2 (18.9)	8.7 (76.0)	12.2 (149.2)	13.0 (172.7)	4.2 (28.2)	5.2 (28.0)	14.9 (228.8)
Last week of October	3.9 (16.3)	3.3 (11.5)	2.8 (8.0)	6.0 (35.8)	4.7 (22.5)	2.8 (8.2)	2.0 (4.0)	5.9 (34.6)	7.1 (56.5)	7.7 (60.0)	8.2 (67.0)	13.5 (183.5)	11.4 (135.8)	4.1 (18.3)	5.6 (32.0)	13.5 (186.2)
LSD (p=0.05)	NS	0.4	NS	NS	NS	0.4	NS	NS	0.9	0.8	NS	NS	1.8	0.7	NS	2.1
Pendimethalin 0.75 kg/ha PE *fb* hand weeding on 20 DAS	3.6 (13.6)	2.7 (7.1)	3.0 (9.3)	5.5 (30.0)	3.8 (14.7)	2.2 (5.1)	2.1 (4.7)	4.9 (24.4)	5.6 (32.2)	4.7 (23.6)	8.6 (74.7)	11.4 (130.4)	10.6 (117.1)	3.4 (12.0)	6.0 (37.3)	12.8 (166.4)
Pendimethalin 0.75 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE on 20 DAS	3.9 (15.3)	2.6 (8.0)	2.6 (6.7)	5.5 (30.0)	5.5 (30.4)	1.7 (4.7)	1.8 (3.3)	6.2 (38.4)	5.8 (35.6)	5.6 (37.3)	8.3 (69.3)	11.9 (142.2)	13.0 (172.0)	2.7 (12.2)	5.1 (26.7)	14.4 (210.9)
Pendimethalin 0.75 kg/ha PE *fb* imazethapyr 50 g/ha PoE on 20 DAS	3.6 (14.0)	2.6 (8.2)	2.9 (8.7)	5.5 (30.9)	5.4 (29.8)	3.0 (9.3)	2.1 (4.3)	6.6 (43.3)	6.9 (48.4)	4.9 (30.4)	8.3 (69.3)	12.1 (148.2)	13.2 (177.3)	4.0 (19.1)	5.9 (34.7)	15.1 (231.1)
Imazethapyr 50 g/ha + quizalofop-ethyl 50 g/ha (tank mix) PoE on 20 DAS	5.1 (26.4)	3.2 (10.2)	2.7 (7.3)	6.6 (44.0)	5.8 (34.2)	3.7 (14.2)	1.9 (3.7)	7.2 (52.1)	8.5 (76.4)	6.9 (49.4)	8.5 (73.3)	14.1 (199.2)	14.4 (209.6)	8.0 (70.2)	5.4 (29.3)	17.5 (309.1)
LSD (p=0.05)	0.3	0.1	0.2	0.5	0.4	0.2	0.2	0.5	0.6	0.5	NS	1.0	1.1	0.4	0.5	1.3
M at S LSD (p=0.05)	0.8	0.5	0.5	1.1	1.0	0.5	0.3	1.2	1.1	1.3	1.1	NS	2.4	1.0	1.0	2.8
S at MLSD (p=0.05)	0.6	0.4	0.4	0.8	0.8	0.4	0.3	0.9	1.0	0.9	NS	1.8	1.9	0.8	0.8	2.2

Note: Figures in the parentheses are original value PE- Pre-emergence; PoE- Post-emergence

Table 3. Effect of dates of sowing and weed management treatments on relative density of weeds on 20 and 40 DAS

Treatment	20 DAS											40 DAS													
	Dm	Eh	Av	Tpm	Co	Ai	Ca	Pm	Cr	Cd	Rc	Dm	Eh	Av	Tpm	Co	Ai	Tp	Ac	Ca	Pm	Ai	Cr	Cd	Rc
Last week of September	24	5	1	14	2	4	4	0	19	4	23	35	1	6	5	3	6	0	1	7	5	2	20	2	9
Second week of October	23	5	6	16	0	0	1	3	22	2	21	24	3	10	7	2	3	4	1	2	11	5	18	2	8
Last week of October	13	0	3	8	0	0	0	20	32	2	21	23	1	5	9	1	4	0	3	3	14	2	24	3	9
Pendimethalin 0.75 kg/ha PE *fb* hand weeding on 20 DAS	8	0	1	30	0	0	1	6	24	6	25	12	2	9	6	1	5	0	0	2	18	5	21	4	15
Pendimethalin 0.75 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE on 20 DAS	23	9	8	7	0	0	0	7	25	4	18	30	5	10	10	1	4	2	3	4	9	2	12	1	8
Pendimethalin 0.75 kg/ha PE *fb* imazethapyr 50 g/ha PoE on 20 DAS	17	0	4	8	2	4	4	5	26	6	23	36	0	3	5	2	9	0	0	5	8	1	22	2	8
Imazethapyr 50 g/ha + quizalofop-ethyl 50 g/ha (tank mix) PoE on 20 DAS	32	4	0	7	0	1	3	14	23	2	15	31	0	6	7	3	0	4	3	4	4	3	28	1	6

Ah: *Abutilon hirtum,* Ai: *Acalypha indica,* Av: *Amaranthus viridis,* Ac: *Ageratum conyzoides,* Co: *Corchorus olitorius,* Ca: *Celosia argentea,* Dm: *Digeria muricata,* Eh: *Euphorbia hirta,* Pm: *Phyllanthus maderaspatensis,* Tpm: *Trianthema portulacastrum,* Tp: *Tridax procumbens,* Cr: *Cyperus rotundus,* Cd: *Cynodon dactylon,* Rc: *Rottboellia cochinchinensis*

Table 4. Effect of dates of sowing and weed management treatment on growth and yield attributes and yield of greengram

Treatment	Plant height (cm)	DMP (kg/ha)	No. of pods/ plant (no.)	No. of seeds/ pod (no.)	100 seed weight (g)	Seed yield (kg/ha)	Cost of cultivation (`/ha)	Net returns (`/ha)	B:C
Last week of September	65.2	4556	26.1	7.9	3.6	850	17116	29634	2.73
Second week of October	60.9	4119	24.3	7.1	3.5	733	17116	23171	2.35
Last week of October	54.4	3615	11.8	6.3	3.0	614	17116	16640	1.97
LSD (p=0.05)	7.9	533	3.0	0.9	0.4	95	-	-	-
Pendimethalin 0.75 kg/ha PE *fb* HW on 20 DAS	64.2	4425	26.1	7.8	3.6	808	17350	27108	2.56
Pendimethalin 0.75 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE on 20 DAS	61.7	4207	24.2	7.2	3.4	757	17105	24512	2.43
Pendimethalin 0.75 kg/ha PE *fb* imazethapyr 50 g/ha PoE on 20 DAS	59.4	4035	23.5	7.0	3.4	730	17255	22895	2.33
Imazethapyr 50 g/ha + quizalofop-ethyl 50 g/ha (tank mix) PoE on 20 DAS	55.3	3720	20.0	6.2	3.1	633	16755	18078	2.08
LSD (p=0.05)	5.1	349	2.0	0.6	0.3	64	-	-	-

g). This is in line with the findings of Sudesh Kumar *et al.* (2019). This result was at par with application of PE pendimethalin 0.75 kg/ha fb PoE quizalofop-ethyl 50 g/ha on 20 DAS (**Table 4**).

Seed yield: The maximum seed yield (850 kg/ha) was recorded under sowing of greengram during last week of September over sowing of greengram on second and last week of October (733 and 614 kg/ha) (**Table 4**). Bobade *et al.* (2018) also reported that early sowing of greengram (June 23) recorded higher yield than late dates of sowing. Among the weed management practices, application of pendimethalin 0.75 kg/ha PE *fb* HW on 20 DAS recorded significantly increased seed yield of greengram (808 kg/ha) due to their effectiveness in weed control as observed by Singh *et al.* (2015) with pendimethalin 1000 g/ha PE +1 hand weeding

Economics

The monetary returns of *Rabi* (winter) greengram decreased with the delay in sowing date (**Table 4**). The maximum net return (₹ 33525/ha) and B:C (2.93) were recorded under sowing of greengram on last week of September with pendimethalin 0.75 kg/ha PE *fb* HW on 20 DAS. This was followed by PE pendimethalin 0.75 kg/ha PE *fb* quizalofop ethyl 50 g/ha PoE on 20 DAS.

It may be concluded that, seeding of greengram during last week of September with pendimethalin 0.75 kg/ha PE *fb* HW on 20 DAS results in better weed management and higher grain yield under rainfed vertisol condition.

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Indian Journal of Weed Science **53**(2): 195–197, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of mulching and herbicides on weeds, yield and economics of tomato grown under drip irrigation system

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Article information

DOI: 10.5958/0974-8164.2021.00037.X

Type of article: Research note

Received : 2 March 2021
Revised : 12 April 2021
Accepted : 15April 2021

Key words
Pendimethalin
Quizalofop-p-ethyl
Mulching
Tomato
Weed control efficiency

ABSTRACT

A field experiment was conducted at Horticulture Polytechnic College, Navsari Agricultural University, Paria, Gujarat, India to determine the effect of mulching and herbicides on weed infestation, yield and economics of tomato cultivation under drip irrigation system. The experiment comprised of four mulches, *viz.*, black polyethylene, silver polythene, red polythene and paddy straw; two herbicide treatments *i.e.* pendimethalin 1.0 kg/ha pre-emergence + one hand weeding at 45 days after transplanting (DAT), pendimethalin 1.0 kg/ha pre-emergence + quizalofop-p-ethyl 0.04 kg/ha post-emergence PoE at 45 DAT along with a weed free treatment and a weedy check. Results revealed that black polythene mulch recorded highest weed control efficiency (37.86%), minimum weed index (0.00%), highest yield (82.45 t/ha), maximum net realization and highest benefit cost ratio (2.20). Therefore, it is suggested that the black polythene (50 µ) mulching may be used for effective weed management and optimal yield of tomato under drip irrigation system.

Tomato (*Solanum lycopersicum*) is one of the most important vegetable crops in India and it is quite popular amongst small and medium-scale commercial farmers due to high net returns. Weeds are the major limiting factor affecting the productivity in drip irrigation based intensive vegetable production system. Weeding and hoeing are common cultural and manual weed management methods for tomato. Manual weeding at right stage is difficult, time consuming and expensive due to intermittent rainfall during rainy season and scanty labour, therefore, farmers rarely adopt manual weeding for weed control. The practice of applying mulches for the production of vegetables is thousands of years old. The use of mulches typically results in higher yields and quality in vegetable crops enhancing profitability for the grower. these are many herbicides that are effective to control weeds in tomato. done to find the feasibility of using mulch materials and herbicides for weed control in tomato under drip irrigation.

A field experiment was carried out at Agriculture Experimental Station, Navsari Agricultural University Paria, Gujarat, India during 2017, 2018 and 2019 to determine effect of different mulches and herbicidal treatments on weed control in tomato under drip irrigation system. The experiment was laid out in randomized block design (RBD) with eight treatments replicated three times. The different weed management treatments were four mulches, *viz.* black polyethylene (50µ), silver polythene (50µ), red polythene (50µ) and paddy straw (5tons/ha); two herbicide treatments *i.e.*pendimethalin 1.0 kg/ha (pre-emergence) + one hand weeding 45 days after transplanting (DAT), pendimethalin 1.0 kg/ha (pre-emergence) + quizalofop-p-ethyl 0.04 kg/ha (post-emergence) at 45 DAT along with a weed free treatment and a weedy check. Forty-day-old uniform seedlings of tomato cv. "*Abhinav*" were transplanted in 5.4 x 3.6 m plots at 90 × 60 cm spacing and irrigated. Mulch treatments were applied before transplanting, and herbicides were applied with the help of knapsack sprayer at the specified time and dose. Weeds were uprooted as and when seen in weed free treatment. Tomato plant height and kind of weeds, *viz.* monocot, dicot and sedges were counted at 60 days after transplanting in 1m^2 quadrate. Cost of cultivation, net returns and benefit cost ratio were also calculated to work out the economics of different weed control strategies and to suggest the best treatment. Statistical analysis was carried out by following the standard methods given by Panse and Sukhatme (1967).

Plant height and density of weeds

Maximum plant height (69.00 cm) was recorded in black polythene mulched plots which was statistically at par with silver coloured polythene mulched plots (**Table 1**), while unweeded control plots recorded the minimum plant height (51.53 cm) at 60 DAT. In the herbicidal treatments (pendimethalin 1.0 kg/ha pre-emergence + 1 hand weeding 45 DAT) and (pendimethalin 1.0 kg/ha pre-emergence + quizalofop-p-ethyl 0.04 kg/ha post-emergence 45 DAT) 60.72 cm and 57.36 cm plant height was recorded, respectively which were statistically at par with each other. The polythene mulched plots recorded higher plant height as plants grown under plastic mulch experienced higher soil temperature, warmer microclimate and weed free environment as compared to straw mulch, herbicidal treatments and unweeded control, which resulted in higher growth of plants. Plastic mulches hinder the evaporation and moderate the soil temperature and moisture conditions that help in better root development and nutrient uptake by plant which ultimately improves the plant growth. Soil thermal regime, a crucial factor for plant growth and development, is influenced by the colour of plastic mulch. The effects of black plastic mulch (BPM), silver plastic mulch (SPM), transparent plastic mulch (TPM) and bare soil on soil temperature regime as well as on growth and yield of rainfed soybean were evaluated in a field experiment (Kader *et al.* 2020). The coloured-mulching significantly ($p<0.05$) increased soybean growth attributes and thus augmented seed yield by 31–34% compared to bare soil. The findings of present study are in close agreement with Khan *et al.* (2015) where longest sponge gourd vines were recorded in black polythene mulched plots. In another study, Bhatt *et al.* (2011) also recorded maximum plant height and spread in summer squash plots mulched with black polythene.

Minimum weed population was recorded in black polythene mulched plots, while unweeded control plots recorded maximum weeds (**Table 1**). The silver and red coloured mulches checked the growth of all kind of weeds more effectively than the herbicidal treatments. Further, silver coloured polythene was statistically superior to red coloured polythene in restricting the number of sedges. Polythene and weed free plots compared to the chemical and unmulched plots showed significantly least weed infestation. Similar results were observed in cassava (Nedunchezhiyan *et al.* 2017) and onion (Dulal Sarkar *et al.* 2019). The cessation of weed growth under mulches might be due to the dark barrier and subsequent photosynthesis inhibition. Low number of weeds under black polythene mulch may be due to high temperature and reduced light availability as compared to other mulches (Bakht *et al.* 2014), reduced germination of light responsive seeds and physically blocking the emergence of most weeds (Edgar 2017). Black colour of the polyethylene absorbed all the incident radiations itself so less light penetration occurred which ultimately checked the weed seed germination and growth (Ngouajio and Ernest 2004).

Weed control efficiency

The highest weed control efficiency was recorded in black polythene mulched plots (37.86%) followed by silver and red coloured polythene mulched plots, while unweeded control recorded zero per cent weed control efficiency (**Table 2**). The variation of weed control efficiency among the different plastic colours may be attributed to their differences on soil temperature and the absorbance and transmittance of solar radiation (Ashrafuzzaman *et al.* 2011). The influence of plastic mulch on weeds may come through trapping radiant energy in clear mulch to create a greenhouse effect (Teasdale and Mohler 2000), while black plastic mulch controls weeds by obstructing photosynthetically active light reaching the ground surface. The lowest weed index

Table 1. Plant height and occurrence of different types of weeds at 60 days after transplanting as affected by different treatments in tomato crop

Treatment	Plant height (cm)	Monocot weeds (no./m^2)	Dicot weeds (no./m^2)	Sedges (no./m^2)
Pendimethalin 1.0 kg/ha (PE) + 1 hand weeding 45 DAT	60.72	3.96 (15.75)	3.59 (13.75)	1.84 (3.51)
Pendimethalin 1.0 kg/ha (PE) + quizalofop-p-ethyl 0.04 kg/ha at 45 DAT (PoE)	57.36	4.05 (16.42)	3.90 (14.85)	2.08 (4.40)
Weed free	62.47	3.33 (11.25)	2.79 (7.98)	1.59 (2.58)
Unweeded control	51.53	5.23 (27.33)	4.62 (21.33)	2.26 (5.19)
Black polythene mulch (50 µ)	69.00	3.23 (10.25)	2.72 (7.73)	1.44 (2.15)
Silver polythene mulch (50 µ)	66.28	3.41 (11.75)	2.85 (8.31)	1.59 (2.58)
Red polythene mulch (50 µ)	63.33	3.57 (12.83)	2.93 (8.75)	1.69 (2.90)
Paddy straw mulch (5t/ha)	59.55	3.97 (15.91)	3.68 (13.75)	1.99 (4.00)
LSD (p=0.05)	3.72	0.42	0.25	0.08

Square root transformed, figures in the parentheses are original values; PE: Pre-emergence; PoE: Post-emergence

Table 2. Effect of different treatments on weed control efficiency, weed index, yield and benefit cost ratio

Treatment	Weed control efficiency (%)	Weed index	Yield (t/ha)	Benefit cost ratio (BCR)
Pendimethalin 1.0 kg/ha (PE) + 1 hand weeding 45 DAT	28.26	17.97	67.97	1.86
Pendimethalin 1.0 kg/ha (PE) + quizalofop-p-ethyl 0.04 kg/ha at 45 DAT (PoE)	26.20	23.50	63.35	1.81
Weed free	32.99	12.88	72.10	1.89
Unweeded control	0.00	47.76	43.16	1.08
Black polythene mulch (50 µ)	37.86	0.00	82.45	2.20
Silver polythene mulch (50 µ)	35.47	4.22	79.29	2.08
Red polythene mulch (50 µ)	33.11	16.33	74.80	1.90
Paddystraw mulch (5t/ha)	25.80	26.03	63.22	1.47

Tomato selling rate- 5 Rs./kg; PE- Pre-emergence; PoE - Post-emergence

(0%) was observed in black polythene mulched plots followed by silver polythene mulched plots, while the maximum weed index was recorded in unweeded control plots (47.79%). The lower weed index in polythene mulched plots might be due to suppression of all type of weeds at critical periods. Similar results were reported by Aniekwe and Nwite (2013) in cucumber, Sha and Karuppaiah (2005) in brinjal and (Choudhary *et al.* 2012) in capsicum.

Economics

The cost of cultivation, gross as well as net realization and benefit cost ratio (BCR) were calculated for each treatment on the bases of inputs applied, tomato yield and prevailing market prices. The highest benefit cost ratio (2.20) was recorded in black polythene mulch treatment, while lowest BCR value was recorded in unweeded control (**Table 2**). Non-chemical weed control such as mulches is required due to herbicide-resistant weeds and environmental pollution caused by herbicides. However, due to environmental demerits of plastic mulch, degradable or biodegradable mulches have been suggested as alternative to black plastic mulch. Several kinds of straw mulches have also been investigated and provide encouraging results for weed control in vegetable crops as evident from this study.

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Indian Journal of Weed Science **53**(2): 198–201, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Mulching effect on weeds and corm production in *Gladiolus hortensis*

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Article information

DOI: 10.5958/0974-8164.2021.00038.1

Type of article: Research note

Received : 21 April 2021
Revised : 10 May 2021
Accepted : 13 May 2021

Key words
Gladiolus

Integrated weed management

Mulch

Weed control efficiency

ABSTRACT

The present experiment was conducted to study the effect of different mulching materials and herbicide application on weed growth parameters, weed control efficiency (WCE) and corm yield in gladiolus variety '*Punjab Glance*'. The experiment was laid out in a randomized block design with three replications each using polythene mulches of colours, *viz*. black 25µ, silver on black 25µ, transparent 25µ and white 50 µ along with rice straw mulch at concentrations of 1.0 kg, 1.5 kg and 2.0 kg/m^2 respectively. The predominant weeds observed were *Oenothera laciniata*, *Coronopus didymus* and *Poa annua* during November to March. The black and silver on black polythene mulch 25µ along with pendimethalin 0.5 kg/ha reported minimum total weed count, total weed fresh and dry weight. The hand-weeded plot showed maximum WCE (100%) followed by pendimethalin 0.5 kg/ha (99.9%) and similar results were recorded under black and silver on black polythene mulch 25µwith 99.8and 99.5% WCE respectively. The black polythene mulch 25µ best promoted plant growth in terms of corms per plant (1.8) cormels per plant (28.5) and corm weight (61.2 g). It suppressed the weeds efficiently with weed count of only (2.3/m^2) from November to March.

Gladiolus hortensis L. is an important bulbous cut flower. It is a native to South Africa's Cape region and is commercially well accepted because of its long spike that bears the florets and wide variation in colours. It is a herbaceous crop that has sword-like leaves. Gladiolus stands in the top few cut flower which has huge demand in the world flower market because of its varied colours, it is being used for bedding purposes, as cut flower, bouquet and pot plant. Weeds compete with the main crop for water, nutrients, space and light and also are alternate hosts to certain insect pests and pathogens. The practice of hand weeding is generally followed for Gladiolus cultivation, but it leads to additional cost. Hence it is necessary to adopt other methods for controlling weeds in this crop. Manual weeding can help us to attain better plant growth and yield but is laborious as well as time-consuming and further the adverse climate obstructs its physical application on the field. Herbicide is an easy option that is cheaper but its repetitive application develops resistance in weeds and also hinders crop growth (Sorkin 1981). Repeated emergence of weeds in the field can reduce the plant growth adversely by 50-100% (Jain *et al.* 2015). Therefore, an experiment was conducted with the objective to evaluate the effects of different mulching materials and herbicide applications on the weed growth and corm yield in Gladiolus.

This present study was carried out at Research Farm, Department of Floriculture and Landscaping, Punjab Agricultural University, Ludhiana, Punjab, India during 2018-2019. The experiment was laid out in a randomized block design with three replications with ten treatments as presented in **Table 1**. The field was well prepared by ploughing and then planking to get a fine soil tilth. The polythene mulches were measured according to the plot and then laid onto the plots and subsequently, the corms were planted at a spacing of 30 x 20 cm. The rice straw was spread as per the treatments after 6-7 days of sowing. The observations on weed parameters in terms of total weed count, total weed dry weight and weed control efficiency for all the weed species recorded in the field, *viz. Oenothera laciniata, Coronopus didymus, Poa annua, Rumex dentatus, Chenopodium album, Cannabis sativus* and *Anagallis arvensis.* The weed density and weed dry weight for the most prominent weed species, *viz. Oenothera laciniata*, *Coronopus didymus* and *Poa annua* was calculated. Corm, cormels and corm weight per plant were recorded. The WCE was worked out using the formulae by (Singh *et al.*2013).

WCE = [(x – y)¸]x´ 100

where,

x = Dry matter of weeds in control (Un-weeded) plot

y = Dry matter of weeds in a treatment.

The comparison done was based upon 5 percent level of significance using (DMRT) Duncan Multiple Range Test. The software used was Statistical Analysis Software (SAS) University edition 15.1.

Effect on weeds

Total weed control was noticed in the hand-weeded plot. Minimum weed count was noticed with pendimethalin 0.5 kg/ha (1.7/m^2) which was at par with rice straw mulch 1.5 kg/m^2 (2/m^2), rice straw mulch 2.0 kg/m^2 (2.1/m^2), rice straw mulch 1.0 kg/m^2 (2.2/m^2), black polythene mulch 25µ (2.3/m^2) and silver on black polythene mulch 25µ (2.9/m^2) (**Table 1**). Minimum fresh (2.8 g/m^2) and dry weight (1.1 g/m^2) of weeds was noticed in pendimethalin 0.5 kg/ha which was at par with black polythene mulch 25µ (1.2 g and 3.1 g/m^2), rice straw mulch 1.5 kg/m^2 (1.4 g and 3.3 g/m^2), rice straw mulch 2 kg/m^2 (1.3 g and 3.4g/m^2) and silver on black polythene mulch 25µ (1.2 g and 3.7g/m^2).

Black and silver on black polythene mulch 25µ along with rice straw mulch 1.0, 1.5, 2.0 kg/m^2 and pendimethalin 0.5 kg/ha showed effective WCE of up to 99%. White polythene mulch 50µ showed lower WCE (61.1%) followed by transparent polythene mulch 25µ (58.9%) and lowest in weedy check plot (0%). The most reliable method for weed suppression was mulching that too especially for annual weeds and it also saves the labour costs as reported by Sethi (1966) in potato.

The plastic mulches are a good aid for reducing the evaporation and transpiration losses of water from the soil and to further restrict the growth of weed under it. The black polythene mulch in specific is very efficient in reducing the weed growth as firstly, it cuts the sunlight required by the weed seed to germinate, and secondly, if they germinate, they die from etiolation due to the absence of the photosynthetically active radiation required to perform photosynthesis. Similar results were recorded in Gladiolus by Salma *et al.* (2016) with the use of plastic mulches resulting in lower weed count, weed fresh and dry weight. Jeevan *et al.* (2016) reported weed dry weight of mere (1.0 g/m^2) by the use of black polythene mulch in tuberose.

The data pertaining to weed count (no./m^2) and dry weight g/m^2 of *Oenothera laciniata, Coronopus didymus* and *Poa annua* in Gladiolus as influenced by mulching and herbicide application are presented in **Table 2**. Total weed control was noticed in the hand-weeded plot throughout the five months. Minimum weed count reported in pendimethalin 0.5 kg/ha which was statistically at par with rice straw mulch 1.0, 1.5, 2.0 kg/m^2. Moreover, black and silver on black polythene mulch 25µ effectively controlled the major weed species throughout the trial. Transparent polythene mulch 25µ and white polythene mulch 50µ showed significantly higher weed count as compared to black and silver on black polythene mulch 25µ. Maximum weed count was recorded in weedy check plot which was significantly higher than the rest treatments throughout the trial.

Table 1. Effect of mulching and herbicide application on total weed count, weed fresh weight, weed dry weight and weed control efficiency (WCE) in Gladiolus

Treatment	Total weed count (no.m^2)	Total weed fresh weight (g/m^2)	Total weed dry weight (g/m^2)	WCE (%)
Black polythene mulch (25 µ)	2.3(13.6)	3.1(9.5)	1.3(0.9)	99.8
Transparent polythene mulch (25 µ)	29.0 (840.3)	29.5(873.3)	18.3(330.5)	58.9
Silver on black polythene mulch (25 µ)	2.9(23.2)	3.7(13.7)	1.2(0.5)	99.5
White polythene (50 µ)	27.8 (774.3)	29.0 (845.4)	18.1(338.1)	61.1
Rice straw mulch (1 kg/m^2)	2.2(13.3)	3.7(13.3)	1.7(2.1)	99.6
Rice straw mulch (1.5 kg/m^2)	2.0 (9.6)	3.3(10.3)	1.4(1.1)	99.8
Rice straw mulch (2 kg/m^2)	2.1(11.2)	3.4(11.8)	1.3(0.8)	99.8
Pendimethalin 0.5 kg/ha	1.7(6.2)	2.8(7.1)	1.1(0.3)	99.9
Hand weeded (fortnight intervals)	1.0 (0)	1.0 (0)	1.0 (0)	100
Weedy check	39.7(1580.1)	41.2(1702.1)	26.9(740.8)	0
LSD (p=0.05)	0.934	0.874	0.097	-

Data is subjected to square root transformation $(\sqrt{x+1})$. In Parentheses are the original values

In column, means that follows the common letter do not differ significantly in Duncan Multiple Range Test (DMRT) at 5% level.

WCE was calculated by simple formula mentioned in review of literature

Minimum weed dry weight was observed in black and silver on black polythene mulch 25µ closely followed by rice straw mulch 1.0, 1.5, 2.0 kg/m^2 and pendimethalin 0.5 kg/ha with a weed dry weight of around (1.0 g/m^2) throughout the trial as these treatments suppressed the weed growth of *Oenothera laciniata, Coronopus didymus* and *Poa annua.* Maximum number of weeds were noticed in weedy-check plot in November and in successive months up to March which was significantly higher than other treatments. Amongst the plastic mulches, transparent polythene mulch 25µ and white polythene mulch 50µ showed lesser ability to supress the weeds

The black mulch doesn't let the photo-synthetically active radiation to be transmitted through the sheet because they absorb most of it, restricting the germination of weeds. black polythene mulch efficiently suppressed the weed throughout the trial because of its ability to absorb most of the incident light and transmitting mere 0.5-1% light. The black and silver on black polythene mulches helped to reduce the dry weight of weeds by 95% and 98% respectively.The transmittance of 80-90% of visible light via the transparent polythene mulch must have triggered the maximum weed growth under it as reported by Rajablariani *et al.* (2012) in tomato. The

Table 2. Effect of mulching and herbicide application on weed growth of *Oenothera laciniata, Coronopus didymus* and *Poa annua* in Gladiolus

Treatment	Weed density/m^2					Weed dry weight g/m^2				
	Nov	Dec	Jan	Feb	Mar	Nov	Dec	Jan	Feb	Mar
Oenothera laciniata										
Black polythene mulch (25µ)	1.8(2.6)	1.2(0.6)	1.4(1.1)	1.5(1.3)	1.3(1)	1.0 (0.1)	1(0)	1(0)	1(0)	1(0)
Transparent polythene mulch (25µ)	8.7(74.9)	8.8(77)	9.7(94.8)	8.4(70.4)	8.1(64.8)	5.8(33.3)	6.2(38.7)	6.5(42.3)	5.9(34.3)	5.6(31.4)
Silver on black polythene mulch (25µ)	2.3(4.6)	2.1(4)	1.1(0.3)	1.3(1)	1.3(1)	1.1(0.2)	1.1(0.2)	1(0)	1(0)	1(0)
White polythene (50µ)	8.3(68.7)	8.4(70.3)	8.8(76.8)	8.4(69.7)	8.3(68.4)	5.5(29.6)	5.8(32.9)	6(36.3)	5.2(26.5)	5.9(34.2)
Rice straw mulch 1 kg/m^2	1.0(0)	1.0(0)	1.8(3)	1.7(2.6)	1.3(1)	1.0(0)	1.0(0)	1.0(0)	1.2(0.6)	1(0)
Rice straw mulch 1.5 kg/m^2	1.0(0)	1.0(0)	1.7(2.3)	1.6(2)	1.1(0.3)	1.0(0)	1.0(0)	1.0(0)	1.1(0.3)	1(0)
Rice straw mulch 2 kg/m^2	1.0(0)	1.0(0)	1.5(1.6)	1.1(0.3)	1.6(1.6)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1(0)
Pendimethalin 0.5 kg/ha	1.0(0)	1.0(0)	1.2(0.6)	1.2(0.6)	1.2(0.6)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1(0)
Hand weeded (fortnight intervals)	1.0(0)	1.0(0)	1(0)	1(0)	1(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1(0)
Weedy check	16(256)	16.5(273)	15.3(236)	14.2(203)	13.7(188)	11.8(139)	11.1(123)	10.9(119)	10(100.8)	13.7(188.8)
LSD (p=0.05)	0.467	0.582	0.695	0.788	0.508	0.223	0.442	0.405	0.572	0.327
Coronopus didymus										
Black polythene mulch (25µ)	1.2(0.6)	1.5(1.5)	1.1(0.3)	1.1(0.3)	1.1(0.3)	1.1(0.2)	1.2(0.5)	1(0)	1(0)	1(0)
Transparent polythene mulch (25µ)	11.1(126.9)	5.4(28.2)	3.9(15.7)	5.7(32.1)	5.7(32.1)	4.5(20.2)	3.9(15.2)	2.8(7.3)	4.2(17.4)	3.7(13.2)
Silver on black polythene mulch (25µ)	1.2(0.6)	1.1(0.3)	1.5(1.3)	1.4(1.3)	1.2(0.6)	1(0)	1(0)	1(0)	1(0)	1(0)
White polythene (50µ)	6.2(45.4)	5.3(35.2)	4.6(23.2)	5.6(32.3)	6.4(43.2)	3.9(15.2)	3.4(11.4)	3.2(10)	3.8(13.7)	4.3(18.1)
Rice straw mulch 1 kg/m^2	1.0(0)	1.0(0)	1.6(1.6)	1.7(2.6)	1.1(0.3)	1.0(0)	1.0(0)	1.0(0)	1.2(0.6)	1.1(0.2)
Rice straw mulch 1.5 kg/m^2	1.0(0)	1.0(0)	1.5(1.3)	1.4(1.3)	1.1(0.3)	1.0(0)	1.0(0)	1.0(0)	1.2(0.8)	1.0(0)
Rice straw mulch 2 kg/m^2	1.0(0)	1.0(0)	1.6(1.6)	1.1(0.3)	1.1(0.3)	1.0(0)	1.0(0)	1.0(0)	1.0(0.1)	1.0(0)
Pendimethalin 0.5 kg/ha	1.0(0)	1.0(0)	1.2(0.6)	1.2(0.6)	1.1(0.3)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Hand weeded (fortnight intervals)	1.0(0)	1.0(0)	1(0)	1(0)	1(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	7.2(54.9)	4.5(20.9)	3.8(16.3)	4.3(19.7)	3.2(9.7)	5.4(28.5)	3.7(13.2)	2.8(7.6)	3.6(12.4)	2.5(5.5)
LSD (p=0.05)	2.431	2.062	1.729	1.349	1.246	0.586	0.613	0.652	0.698	0.367
Poa annua										
Black polythene mulch (25µ)	1.3(1)	1.5(1.3)	1.1(0.3)	1.1(0.3)	1.1(0.3)	1(0)	1(0)	1(0)	1(0)	1(0)
Transparent polythene mulch (25µ)	5.5(31.9)	5.5(37.6)	5.7(33.2)	7.4(55.2)	8(65.2)	3.1(9.2)	3.3(10.7)	3.6(12.1)	4.9(23.4)	5.1(26.3)
Silver on black polythene mulch (25µ)	1.7(2)	1.9(3)	1.2(0.6)	1.2(0.6)	1.6(1.6)	1(0)	1(0)	1(0)	1(0)	1.1(0.3)
White polythene (50µ)	4.2(19.4)	7.8(67.1)	5.9(35.9)	6.3(39.2)	8.9(78.8)	1.6(1.7)	5.6(35.2)	3.3(10.2)	4(15.3)	6.4(40.2)
Rice straw mulch 1 kg/m^2	1.0(0)	1.0(0)	1.2(0.6)	1.3(1)	1.1(0.3)	1.0(0)	1.0(0)	1.0(0)	1.1(0.3)	1(0)
Rice straw mulch 1.5 kg/m^2	1.0(0)	1.0(0)	1.5(1.3)	1.1(0.3)	1.1(0.3)	1.0(0)	1.0(0)	1.0(0)	1(0)	1(0)
Rice straw mulch 2 kg/m^2	1.0(0)	1.0(0)	1.8(2.3)	1.4(1.3)	1.6(1.6)	1.0(0)	1.0(0)	1.0(0)	1.2(0.6)	1.2(0.6)
Pendimethalin 0.5 kg/ha	1.0(0)	1.0(0)	1.2(0.6)	1.3(1)	1.3(1)	1.0(0)	1.0(0)	1.0(0)	1.1(0.3)	1.3(0.8)
Hand weeded (fortnight intervals)	1.0(0)	1.0(0)	1(0)	1(0)	1(0)	1.0(0)	1.0(0)	1.0(0)	1(0)	1(0)
Weedy check	6.2(45.3)	9.2(84.9)	7.7(60)	6.7(48.4)	7.4(61.1)	1.8(2.2)	6.1(37.2)	5(24.3)	3.9(14.8)	5.3(34.3)
LSD (p=0.05)	2.398	2.744	1.587	1.642	1.868	0.343	1.592	0.379	0.532	1.781

Data is subjected to square root transformation ($\sqrt{x+1}$) in parentheses are the original values

Table 3. Effect of mulching and herbicide application on corms per plant, corm weight per plant and cormels per plant in Gladiolus

Treatment	No. of corms/plant	Corm weight/plant (g)	Cormels/plant
Black polythene mulch 25 µ	1.8	61.2	28.5
Transparent polythene mulch 25 µ	1.7	59.2	27.8
Silver on black polythene mulch 25 µ	1.7	58.1	24.2
White polythene 50 µ	1.6	59.2	25.6
Rice straw mulch 1.0 kg/m^2	1.2	48.3	22.9
Rice straw mulch 1.5 kg/m^2	1.2	47.3	22.4
Rice straw mulch 2.0 kg/m^2	1.1	48	22.3
Pendimethalin 0.5 kg/ha	1.4	54	24.6
Hand weeded (fortnight intervals)	1.6	56.1	27.3
Weedy check	1.2	47	21.8
LSD (p=0.05)	0.245	3.497	3.497

black, silver on black and rice straw mulches were able to restrict the incident light hence were able to obstruct the weed germination in it on the other hand transparent and white plastic mulch by transmitting most of the incident light through it helped in weed seed germination.

Corm yield

Maximum number of corms/plant was noticed in the plot with black polythene mulch 25µ (1.8) so did the maximum number of cormels/plant (28.5) and the maximum corm weight (61.2 g) closely followed by transparent polythene mulch 25µ, silver on black polythene mulch 25µ and white polythene mulch 50µ (**Table 3**). All these treatments presented a non-significant difference for corm yield *viz.* corms per plant, corm weight and cormels per plant in Gladiolus. The plastic mulch treatments outperformed the rest treatments in accordance to corm yield. These results were in line with Kumari *et al* (2013) as the study reported the maximum number of corms produced were under the mulched plot and lesser number of corms produced in non-mulched plots in Gladiolus. These findings were in line with Baladha (2018) as the report exhibits that the corm yield was higher when harvested from the mulched plots. Jat (2017) reported maximum corm weight observed in the mulched plots than in the non-mulched plots in Gladiolus.

The mulch tends to provide optimum soil temperature for root growth and aggravates the soil microbial activity that leads to better uptake of nutrients and minerals form the soil by the plant. Mulching maintains adequate soil temperature regularly and prevents evaporation losses which helps the plant to efficiently perform photosynthesis which in turn helps maintaining a better accumulation of photosynthates. This may be the reason for good corm yield in the mulched plots for gladiolus as reported by Jat (2017).

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Indian Journal of Weed Science **53**(2): 202–205, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Response of weeds to different herbicides and their time of application in clusterbean

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Article information

DOI: 10.5958/0974-8164.2021.00039.3

Type of article: Research note

Received : 21 September 2020
Revised : 25 April 2021
Accepted : 27 April 2021

Key words

Clusterbean, Herbicide, Imazethapyr, Pendimethalin, Weed control

ABSTRACT

A field experiment was conducted under loamy sand soil during *Kharif* (rainy season), 2018 at Swami Keshwanand Rajasthan Agricultural University, Bikaner to evaluate the bio-efficacy of herbicides in clusterbean as affected by time of application. Results revealed that imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) and pendimethalin + imazethapyr at 0.80 kg/ha as PE resulted in the lowest weed density and dry weight of both monocot and dicot weeds. Higher weed control efficiencies were also noted under these treatments. Plant height, pods per plant, seeds per pod and seed and straw yields, net returns and benefit: cost ratio were also superior with imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) and pendimethalin + imazethapyr at 0.80 kg/ha as PE compared to the other treatments.

Clusterbean (*Cyamopsis tetragonoloba*) popularly known by its vernacular name "guar", is an important drought-hardy leguminous crop. It is mainly grown under rainfed condition in arid and semi-arid regions of Rajasthan during *Kharif* (rainy) season. Seeds of guar contain 28–33% gum. Clusterbean is mainly cultivated in marginal and rainfed areas where inadequate weed management is a major constraint in harnessing its production potential. Being a rainy season crop, it suffers badly due to severe competition by mixed weed flora. Saxena *et al.* (2004) reported yield reduction of 53.7% due to weed infestation. Hand-weeding is a traditional and effective method of weed control, but untimely rains, unavailability of labour on time and higher labour cost are the major limitations of manual weeding. Under such a situation, the only alternative that needs to be explored is the use of suitable herbicide which may be effective and economically viable. Application of pendimethalin at 0.75–1.0 kg/ha as pre-emergence was effective against weeds in clusterbean (Dhaker *et al.* 2009), but inadequate moisture and prevailing western winds at time of sowing in this arid region resulted in surface soil-moisture deficit which reduces the efficiency of pre-emergence herbicides (Punia *et al.* 2011). Herbicide application time is an important aspect and has its own importance. Application of herbicide at the time of sowing reduced the weed load at early stage while application of herbicide at post-emergence may be helpful to reduce the quantity of herbicide. To control mix flora of weeds, herbicide mixtures can be used to increase the efficacy of weed control. However, information on use of herbicide mixtures in clusterbean is meager and therefore, an attempt has been made to test some pre- and post-emergence herbicide mixtures in clusterbean.

A field experiment was carried out during the *Kharif* season of 2018 at Instructional farm of Swami Keshwanand Rajasthan Agricultural University, Bikaner. Fifteen treatments consists of weedy check, weed free, one hand weeding at 25 DAS, pendimethalin at 0.75 kg/ha as PE, pendimethalin at 0.75 kg/ha as PPI, pendimethalin + imazethapyr at 0.80 kg/ha as PPI, pendimethalin + imazethapyr at 0.80 kg/ha as PE, pendimethalin + oxyfluorfen at 0.45 kg/ha as PPI, pendimethalin + oxyfluorfen at 0.45 kg/ha as PE, pendimethalin + oxyfluorfen at 0.56 kg/ha as PPI, pendimethalin + oxyfluorfen at 0.56 kg/ha as PE, imazethapyr + imazamox at 40 g/ha as PoE (20 DAS), imazethapyr + imazamox at 50 g/ha as PoE (20 DAS), oxyfluorfen at 150 g/ha as PE and oxyfluorfen at 50 g/ha as PoE (20 DAS), was laid out in a randomized block design with three replications. The soil of the experimental field was loamy sand with low in organic carbon (0.11%), available nitrogen (81.41 kg/ha), available phosphorus (32.4 kg/ha) and medium in available potassium (328 kg/ha) with pH 8.4. Clusterbean variety '*RGC 1066*' was sown on 17 July 2018 with crop geometry of 30 × 10 cm under recommended package of practices. The total rainfall received during the season was 230.2 mm with 8 rainy days. Fertilizers were applied uniformly through urea and diammonium phosphate at the rate of 20 kg N and 40 kg P/ha. Monocot and dicot weeds were counted from randomly selected area of 0.25 m^2 using 0.5 x 0.5 m quadrant at 30 DAS and at harvest and converted into one square meter. Weeds plants were dried at 65°C for 48 h before determining dry weight. The data on total weed count and weed dry matter were subjected to square root transformation (x+0.5) to normalize their distribution (Gomez and Gomez 1984).

Effect on weed

The major weed flora of experimental field consisted of *Cenchrus biflorus, Digera arvensis, Corchorus trilocularis, Tribulus terrestris, Cleome viscose, Phyllanthus niruri, Amaranthus viridis, Cynodon dactylon* and *Cyperus rotundus*. Among the weed-management practices, imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) showed significant reduction in the density and dry weight of weeds in clusterbean than the weedy check and the other herbicide treatments and found at par with imazethapyr + imazamox at 40 g/ha as PoE (20 DAS) and pendimethalin + imazethapyr at 0.80 kg/ha as PE (**Table 1**). This was simply due to the fact that both the treatments were almost the same in controlling in early as well as late flushes of the weeds. Punia *et al.* (2011) also reported better control of weeds in clusterbean with the use of imazethapyr. Further, pendimethalin + imazethapyr at 0.80 kg/ha as PE performed very well in controlling all the categories of weeds. This treatment was found significantly superior to weedy check. The superiority of this treatment in controlling monocot weeds over rest ones was because of the fact that early growth of monocot weeds was checked by pendimethalin + imazethapyr. Similar results were also reported by Samant and Mohanty (2017) in mungbean. Imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) belongs to group of imidazolinone. It is selective and applied as post-emergence with a view to control late emerging weeds. It inhibits the plastid enzyme acetolactate syntheses in plants which catalyses the first step in the biosynthesis of essential branched chain amino acids (Valine, leucine, isoleucine). Saltoni *et al.* (2004) suggested that imazethapyr is an imidazolinones herbicide, which is absorbed both by the roots and the shoots. It can effectively control a broad spectrum of weeds. Results also corroborate with the findings of Sangeetha *et al.* (2013) and Khairnar *et al.* (2014). Imazethapyr + imazamox at 50 g/ha as PoE (20 DAS), imazethapyr + imazamox at 40 g/ha as PoE (20 DAS) and pendimethalin + imazethapyr at 0.80 kg/ha as PE were found to be among more effective treatments that controlled the weeds to the extent of 90.64, 83.90 and 80.91%, respectively (**Table 2**). This variation in weed control efficiency is directly associated with the weed density under these treatments. Inhibition of germination of weeds and their growth following application of different herbicides might have reduced the growth of weeds causing mortality of weeds as discussed earlier in the text. These seem to be the most spectacular reasons of accumulating lesser density of weeds and as a consequence of higher weed control efficiencies.

Table 1. Effect of weed control measures on weed density in clusterbean

Treatment	Weed density (no./m^2)			Weed dry weight (g/m^2)		
	Monocot	Dicot	Total	Monocot	Dicot	Total
Pendimethalin at 0.75 kg/ha as PE	4.46(20.3)	4.04(16.3)	5.98(38.3)	17.43(312.0)	16.97(301.7)	24.35(613.7)
Pendimethalin at 0.75 kg/ha as PPI	5.81(35.7)	5.27(28.0)	7.84(63.7)	21.31(496.3)	19.69(408.3)	29.09(905.0)
Pendimethalin + imazethapyr at 0.80 kg/ha as PPI	4.42(19.7)	4.17(17.0)	6.05(36.7)	19.20(369.7)	13.95(198.3)	23.83(568.0)
Pendimethalin + imazethapyr at 0.80 kg/ha as PE	3.55(12.3)	3.17(9.7)	4.74(27.7)	14.30(215.0)	12.06(148.3)	19.00(363.3)
Pendimethalin + oxyfluorfen at 0.45 kg/ha as PPI	5.67(32.3)	5.51(30.3)	7.93(62.7)	24.04(718.7)	21.73(480.0)	34.15(1198.7)
Pendimethalin + oxyfluorfen at 0.45 kg/ha as PE	5.90(36.7)	5.24(28.7)	8.10(65.3)	22.98(581.7)	21.43(492.7)	32.78(1074.3)
Pendimethalin + oxyfluorfen at 0.56 kg/ha as PPI	5.06(25.7)	5.87(34.3)	7.71(60.0)	21.51(562.3)	23.09(546.3)	32.06(1108.7)
Pendimethalin + oxyfluorfen at 0.56 kg/ha as PE	6.03(36.3)	4.73(22.0)	7.66(58.3)	23.47(551.7)	18.67(352.3)	30.07(904.0)
Imazethapyr + imazamox at 40 g/ha as PoE (20 DAS)	3.07(9.0)	2.73(7.3)	4.10(16.3)	10.83(118.7)	10.03(104.0)	14.92(222.7)
Imazethapyr + imazamox at 50 g/ha as PoE (20 DAS)	2.44(5.7)	2.32(5.0)	3.29(10.7)	8.24(70.3)	7.90(64.3)	11.40(134.7)
Oxyfluorfen at 150 g/ha as PE	6.78(46.0)	5.51(30.3)	8.72(76.3)	31.23(996.3)	22.93(533.0)	38.77(1529.3)
Oxyfluorfen at 50 g/ha as PoE (20 DAS)	6.29(39.3)	5.68(32.0)	8.45(71.3)	20.61(429.3)	21.92(494.0)	30.11(923.3)
One hand weeding at 25 DAS	5.22(27.7)	4.72(22.7)	7.00(50.3)	20.52(421.3)	20.20(409.3)	28.79(830.7)
Weedy check	7.72(59.3)	7.52(56.3)	10.77(115.7)	28.33(805.3)	31.51(1005.7)	42.43(1811.0)
Weed free	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.00)	0.71(0.0)	0.71(0.0)
LSD (p=0.05%)	0.80	0.80	0.82	6.20	3.57	5.17

Values transformed to $\sqrt{x+0.5}$ and actual values are in parentheses

Effect on crop

Pendimethalin at 0.75 kg/ha as PE, pendimethalin + imazethapyr at 0.80 kg/ha as PE, imazethapyr + imazamox at 40 g/ha as PoE (20 DAS) and imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) recorded significantly higher yield attributes *i.e.* pods per plant and seeds per pod compared to weedy check and other treatments and were statistically at par with weed free (**Table 3**). This was attributed to minimum infestation of weeds together with lesser competition for other growth resources *i.e.* light, space, water, nutrients. Thus, reduced crop-weed competition resulted into overall improvement in crop growth as reflected by plant height consequently resulted into better development of reproductive structure and translocation of photosynthetes into the sink. Among the herbicide performance of imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) was found significantly superior in increasing number of pods per plant and seed per pods over pendimethalin at 0.75 kg/ha as PPI, pendimethalin + oxyfluorfen at 0.45 kg/ha as PPI, pendimethalin + oxyfluorfen at 0.45 kg/ha as PE, pendimethalin + oxyfluorfen at 0.56 kg/ha as PPI, pendimethalin + oxyfluorfen at 0.56 kg/ha as PE. The results corroborate with the findings of Singh *et al.* (2018).

Pendimethalin + imazethapyr at 0.80 kg/ha as PE, imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) and imazethapyr + imazamox at 40 g/ha as PoE (20 DAS) recorded significantly higher yields to weedy check and were statistically at par with weed free. Amongst herbicide treatments, performance of pendimethalin + imazethapyr at 0.80 kg/ha as PE was found significantly superior in enhancing the seed, straw and biological yields over rest of herbicides. Our results confirmed the findings of Kumar *et al.* (2016). The reduced crop weed competition caused significant increase in plant height and yield attributes ultimately led to higher seed yield of clusterbean. The significant improvement in seed yield as a result pendimethalin + imazethapyr 0.80 kg/ha as PE and imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) could be ascribed to the fact that yield of crop depends on several yield components which are interrelated. Weed index also witnessed lower value due to these treatments in comparison to weedy check (**Table 2**). The variation in crop-weed competition under different treatments as associated with variation in weed biomass production was eventually reflected in the weed competition indices. Results showed that imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) exhibited the lowest weed competition of 6.44 per cent, as against of 66.07 per cent noted under weedy check in comparison to weed free treatment and maximum under oxyfluorfen at 150 g/ha as PE (96.58).

Imazethapyr + imazamox at 40 g/ha as PoE (20 DAS) and pendimethalin + imazethapyr at 0.80 kg/ha as PE were noted to be the next superior treatments wherein yield reduction due to presence of weeds was 8.85 and 6.88%, respectively as compared to weed free. The higher dry weight by weeds and corresponding reduction in grain yield appeared to be directly associated with variation in weed competition indices among different treatments. These results were in accordance with the findings of Yadav *et al.* (2015) and Kaur *et al.* (2016).

Table 2. Effect of weed control measures on weed control efficiency and weed index in clusterbean

Treatment	Weed control efficiency (%)			Weed index (%)	Plant height (cm)	No. of pods/ plant	No. of seeds/ pod
	Monocot	Dicot	Total				
Pendimethalin at 0.75 kg/ha as PE	66.52	70.29	68.73	17.32	115.47	43.87	8.27
Pendimethalin at 0.75 kg/ha as PPI	41.24	47.61	45.69	30.85	109.76	39.33	8.00
Pendimethalin + imazethapyr at 0.80 kg/ha as PPI	67.70	69.59	68.51	18.01	111.83	43.23	8.40
Pendimethalin + imazethapyr at 0.80 kg/ha as PE	79.57	82.42	80.91	6.88	116.41	47.00	8.47
Pendimethalin + oxyfluorfen at 0.45 kg/ha as PPI	46.63	44.35	45.55	30.43	104.30	40.20	8.40
Pendimethalin + oxyfluorfen at 0.45 kg/ha as PE	38.54	47.84	43.58	58.22	85.21	32.40	7.80
Pendimethalin + oxyfluorfen at 0.56 kg/ha as PPI	57.69	37.01	48.39	34.72	103.46	38.05	7.97
Pendimethalin + oxyfluorfen at 0.56 kg/ha as PE	36.03	59.59	49.37	61.89	82.94	30.07	7.73
Imazethapyr + imazamox at 40 g/ha as PoE (20 DAS)	80.84	87.40	83.90	8.85	116.07	47.01	8.53
Imazethapyr + imazamox at 50 g/ha as PoE (20 DAS)	89.89	91.24	90.64	6.44	117.94	47.58	8.60
Oxyfluorfen at 150 g/ha as PE	22.41	43.77	34.39	96.58	43.88	13.40	6.80
Oxyfluorfen at 50 g/ha as PoE (20 DAS)	33.50	41.45	38.62	85.04	67.29	20.53	7.27
One hand weeding at 25 DAS	54.69	58.52	56.91	32.34	103.64	41.27	7.97
Weedy check	0.00	0.00	0.00	66.07	93.10	26.47	7.20
Weed free	100.00	100.00	100.00	0.00	124.52	48.57	8.87
LSD (p=0.05%)					5.81	4.77	0.44

Table 3. Effect of weed control measures on weed density in clusterbean

Treatment	Yield (t/ha)			Cost of cultivation (x10^3 ₹/ha)	Gross returns (x10^3 ₹/ha)	Net returns (x10^3 ₹/ha)	B:C ratio
	Seed	Straw	Biological				
Pendimethalin at 0.75 kg/ha as PE	1175	3.95	5.13	18.80	56.77	37.97	3.02
Pendimethalin at 0.75 kg/ha as PPI	982	3.63	4.61	18.80	48.13	29.33	2.56
Pendimethalin + imazethapyr at 0.80 kg/ha as PPI	1154	3.75	4.91	19.13	55.52	36.39	2.90
Pendimethalin + imazethapyr at 0.80 kg/ha as PE	1310	4.24	5.55	19.13	62.99	43.86	3.29
Pendimethalin + oxyfluorfen at 0.45 kg/ha as PPI	978	3.31	4.29	19.20	47.32	28.12	2.46
Pendimethalin + oxyfluorfen at 0.45 kg/ha as PE	589	1.97	2.56	19.20	28.45	9.25	1.48
Pendimethalin + oxyfluorfen at 0.56 kg/ha as PPI	920	3.20	4.12	19.51	44.66	25.15	2.29
Pendimethalin + oxyfluorfen at 0.56 kg/ha as PE	537	1.72	2.25	19.51	25.76	6.25	1.32
Imazethapyr + imazamox at 40 g/ha as PoE (20 DAS)	1283	4.14	5.43	18.98	61.65	42.66	3.25
Imazethapyr + imazamox at 50 g/ha as PoE (20 DAS)	1322	4.21	5.54	19.25	63.43	44.18	3.30
Oxyfluorfen at 150 g/ha as PE	48	0.19	0.24	19.70	2.38	-17.31	0.12
Oxyfluorfen at 50 g/ha as PoE (20 DAS)	211	0.82	1.03	18.51	10.39	-8.11	0.56
One hand weeding at 25 DAS	962	3.46	4.42	20.04	46.96	26.92	2.34
Weedy check	482	1.82	2.30	17.91	23.68	5.77	1.32
Weed free	1418	4.25	5.66	23.23	67.47	44.23	2.90
LSD (p=0.05%)	125	0.51	0.59	-	-	-	-

Economics

The net returns of ₹ 44234/ha were obtained with weed free, which was followed by ₹ 44185/ha under imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) (**Table 3**). As far as benefit cost ratio is concerned maximum benefit: cost ratio was also obtained with imazethapyr + imazamox at 50 g/ha as PoE (20 DAS) (3.30) followed by application of pendimethalin + imazethapyr at 0.80 kg/ha as PE (3.29). The lowest benefit: cost of 1.32 was recorded under weedy check. Among the weed control treatments, minimum net return and B:C were obtained under oxyfluorfen at 150 g/ha as PE and the respective value of net returns and benefit: cost ratio under this treatment were ₹ 17312/ha and 0.12. The higher seed yield recorded with this treatment might be responsible for higher net return. These results were in agreement with the findings Sangeetha *et al.* (2013) and Pratap *et al.* (2018).

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Indian Journal of Weed Science **53**(2): 206–208, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Additional weed hosts of *Ralstonia solanacearum* recorded in West Bengal

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Article information

DOI: 10.5958/0974-8164.2021.00040.X

Type of article: Research note

Received : 4 February 2021
Revised : 15 June 2021
Accepted : 18 June 2021

Key words

Bacterial wilt, *Ralstonia solanacearum*, Sundarbans, Wild host, Weeds

ABSTRACT

Ten weeds/wild plants belonging to six families, *viz. Martynia annua*, *Cleome viscosa*, *Physalis minima*, *Cestrum diurnum*, *Amaranthus spinosus*, *Costus speciosus*, *Croton sparsiflorus*, *Datura metel*, *Solanum indicum* and *Solanum sisymbriifolium* were recorded as the host plants of *Ralstonia solanacearum* from Sundanban region of West Bengal, India. Among them, *Martynia annua* and *Cleome viscose* were recorded first time from India. These weed hosts enable the survival of the bacterial pathogen in absence of crop hosts, and play a significant role in widespread incidence of bacterial wilt of cultivated vegetable crops in West Bengal.

The bacterium, *Ralstonia solanacearum* (Smith) Yabuuchi *et al.* infects many economically important crop plants and a number of weeds. More than 200 plant species of 55 families were reported as hosts of this bacterium (Kelman 1953, Hayward 1994). Weed/wild hosts of the bacterium were reported from different parts of the world and they increase its survival potential in the nature. Some of the weed hosts of the pathogen were reported from India (Chaudhuri and Khatua 1982, Samaddar *et al.* 1998, Mondal 2004). The survival of the bacterium in weed/wild hosts may be one of the reasons for the devastation of this disease in West Bengal. Hence, studies were undertaken to identify weed/wild hosts from different parts of Sundarban region of West Bengal.

Surveys were conducted in 13 different blocks of South 24 Parganas (Sagar, Namkhana, Kakdwip, Patharpratima, Kultali, Mathurapur-I, Mathurapur-I, Jaynagar-I, Jaynagar-II, Canning-I, Canning-II, Basanti and Gosaba) and six different blocks of North 24 Parganas (Hingalganj, Hasnabad, Haroa, Sandeshkhali-I, Sandeshkhali-II and Minakhan) under Sundarban region of West Bengal (India) for three consecutive years (2012-2014) to record the incidence of bacterial wilt on wild plants or weeds. Incidence of the disease on weeds or wild plants in and around crop fields, barren lands, road side *etc.* was recorded during every month. In this survey, bacterial nature of the disease was confirmed directly by ooze test in the field condition, and through isolation in selective medium (Granada and Sequeira 1983, Kelman 1954), morphological and biochemical studies in laboratory condition and also through pathogenicity test by stem injection and root inoculation method (Kelman 1953, Kelman 1954, Hayward 1964).

Weed hosts of the pathogen

During survey, several weeds/wild plants were recorded as the hosts of this bacterium, presented in **Table 1**. In the present study, wilting of ten weeds/wild plants was observed. These were *M. annua* **(Plate 1a, 1b, 1c)**,*C. viscose* **(Plate 1e and 1f)**, *P. minima* **(Plate 1h)**, *C. diurnum* **(Plate 1g)**, *A. spinosus, C. sparsiflorus, Solanum indicum*, *S. sisymbriifolium, C. Speciosus* **(Plate 1d)** and *D. metel* grown abundantly on the roadside, barren and fallow lands, ridges of the field, and in an around the fruit orchards and vegetable fields. Except *M. annua* and *C. viscosa*, all other eight weeds reported earlier as the hosts of this destructive plant pathogen (Mondal *et al.* 2014). The most predominant weeds in brinjal fields and surrounding area were *A. spinosus* and *P. minima*.

C. diurnum and *C. speciosus* were found to grow widely in road side, barren and fallow lands and in an around the fruit orchard in some areas of North 24 Parganas and South 24 Parganas district. Some cultivars of *C. diurnum* used as ornamental plant and

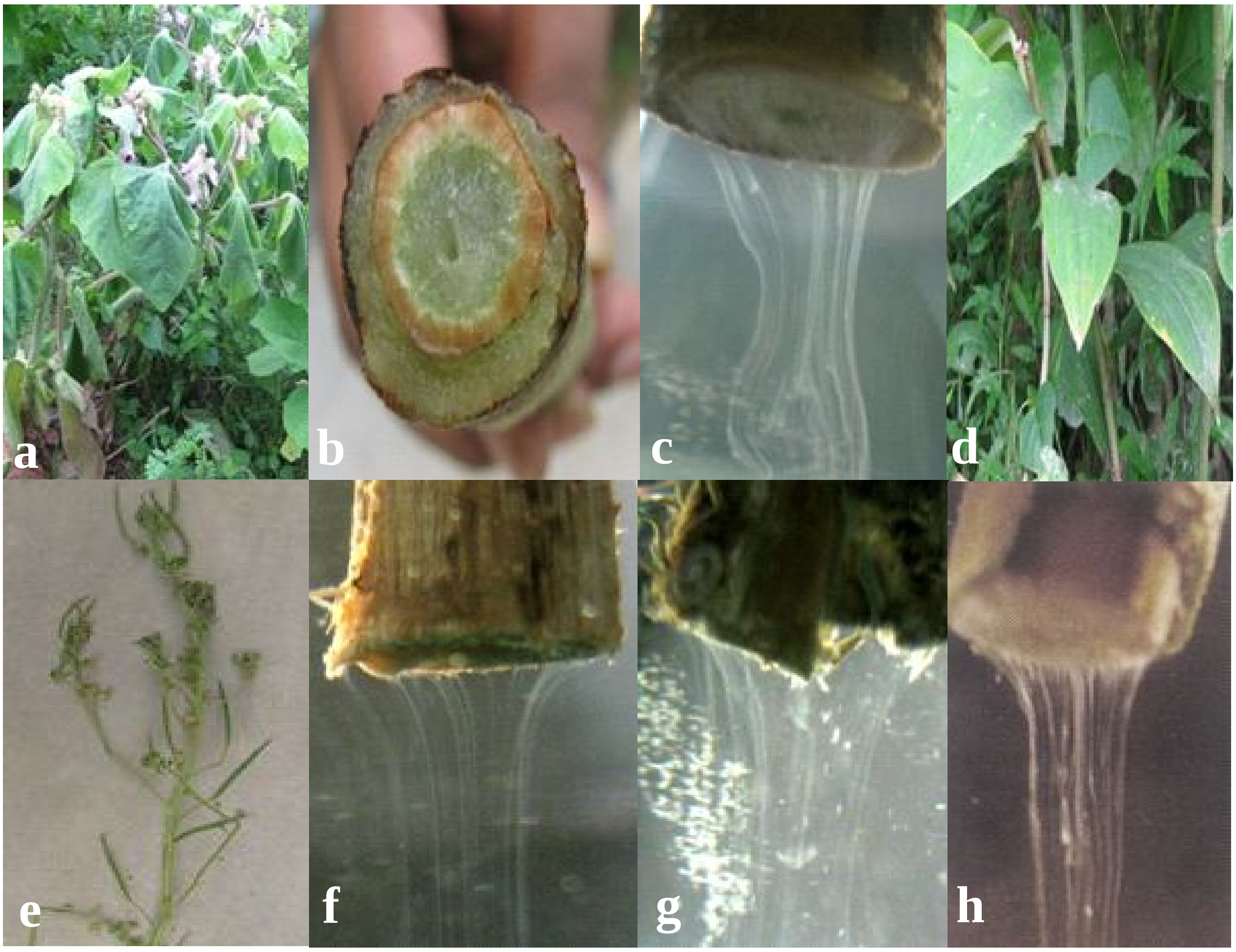

Plate 1. Bacterial wilt of different weeds
a: Bacterial wilt of *Martyniaannua;* **b**: Cross section of *Martyniaannua* showing vascular browning; **c**: Bacteria oozing out from the cut end of *Martyniaannua;* **d**: Bacterial wilt of *Costusspeciosus;* **e**: Bacterial wilt of *Cleomeviscosa;* **f**: Bacteria oozing out from the cut end of *Cleome viscosa;* **g**: Bacteria oozing out from the cut end of *Cestrum diurnum;* **h**: Bacteria oozing out from the cut end of *Physalis minima*

C. speciosus as medicinal plants. According to Mondal *et al.*(2014), *R. solanacearum* survives on *C. speciosus* and *C. diurnum* throughout the season in latent form or in infectious stage. The weeds like *A. spinosus* and *D. metel* were also recorded inside the orchard as latent hosts. Besides, *A. spinosus* grown widely near the rail line (Hasnabad, Canning, Jaynagar railway station) carried this destructive bacterial plant pathogen also. Not only that, *C. sparsiflorus* grown on barren or fallow land and road side acted as reservoir of the bacterium. Mondal *et al.* (2012) recorded the trend of survival strategy of *R. solanacearum* on different hosts from West Bengal. In case of wild hosts the bacterial pathogen survives possibly all over the year which is a major threat for vegetable cultivation.

High temperature along with rainfall favours the bacterial wilt of weeds/wild plants. In majority of the cases, wilting process started from the last week of June (Av. Tmax. 34°C and Tmin. 22°C). The maximum wilt intensity was recorded during August-September (Av. Tmax. 32°C and Tmin.25°C) and death of such plants ceased at the end of October (Av. Tmax. 28°C and Tmin. 22°C) or first week of November (Av. Tmax. 27°C and Tmin. 18°C). Natural infection of such widely grown common weeds/wild plants helped in survival of the bacterial pathogen in absence or presence of main hosts, and for inoculum build up. The active inoculum from weed hosts during July-August could easily be transported to nearby fields through rain and irrigation water run-off that initiate disease in crop plants. The findings were in conformation with the earlier reports (Mondal *et al.* 2014).

Pathogenicity study

In the present study, bacterial wilt disease was recorded on ten wild plants. Among them, nine isolates were pathogenic on brinjal, tomato, potato and chilli indicating race-1 and one isolate from *C.*

Table 1. Weeds/wild plants infested by bacterial wilt in West Bengal

Vernacular name	Scientific name	Family	Location
Bug Noki	*Martynia annua* L.	Martyniaceae	Jaynagar I & II
Hurhure	*Cleome viscose* L.	Cleomaceae	
Bantepari	*Physalis minima* L.	Solanaceae	Gosaba, Basanti, Sandeshkhali II, Jaynagar I & II
Hasnuhana	*Cestrum diurnum* L.	Solanaceae	Jaynagar I & II,
Kanta Note	*Amaranthus spinosus* L.	Amaranthaceae	Hasnabad, Canning I, Jaynagar
Costus	*Costus speciosus* (Koen ex. Retz.) Sm.	Zingiberaceae	Basanti, Gosaba, Hingalganj
Bonmarich	*Croton sparsiflorus* Morong.	Euphorbiaceae	All the 19 blocks under Sundarban region
Dhutura	*Datura metel* L.	Solanaceae	Gosaba, Jaynagar I, Kultali,
Sticky Nightshade	*Solanum sisymbriifolium* Lam.	Solanaceae	Gosaba, Namkhana, Sandeshkhali I, Hasnabad
Brihoti	*Solanum indicum* L.	Solanaceae	Canning I & II, Basanti, Gosaba

Table 2. Pathogenicity of isolates of *R. solanacearum* from weeds/wild plants

Sources of isolates	Stem injection and root inoculation method Response of pathogenicity test				
	Brinjal	Tomato	Potato	Chilli	Ginger
Martynia annua	+ +	+ +	+ +	+ +	-
Cleome viscosa	+ +	+ +	+	++	-
Physalis minima	+ +	+ +	+	+ +	-
Cestrum diurnum	+ + +	+ + +	+ +	+ +	-
Amaranthus spinosus	+ + +	+ + +	+ +	+ +	-
Costus speciosus	-	-	-	-	+
Croton sparsiflorus	+ +	+ +	+	+ +	-
Datura metel	+ +	+ +	+	+ +	-
Solanum sisymbriifolium	+ +	+ +	+	+ +	-
Solanum indicum	+ +	+ +	+	+ +	-

+ + + = Very rapid wilting, + + = Rapid wilting, + = Moderate wilting, - = No wilting

Speciosus was on ginger only indicating race-4 of the pathogen. The isolates were dissimilar by means ofboth host specificity and extent of wilting **(Table 2)**. Highly virulent isolates of *R. solanacearum* from *C. diurnum* and *A. spinosus* developed symptoms rapidly on brinjal and tomato. Existence of variation among isolates of the bacterium infecting different crops or wild plants is known (Buddenhagen *et al.* 1962, Lozano and Sequeira 1970, Kam and Quimio 1977, He *et al.* 1983, Hayward 1994).

Bacterial wilt is a most destructive important vascular disease throughout the world for its wide host range and soil borne in nature. The weeds/wild plants recorded in the present study not only harboured the pathogen in off-season, but also acted as collateral hosts, which appeared to play a significant role in widespread incidence of bacterial wilt of cultivated vegetable crops in West Bengal. Bacteria ooze out from such plants and the active inoculum could easily be transported to nearby other crop fields. So, identification of weeds/wild hosts in and around the crop fields during crop season or off season followed by proper destruction is important for future planning of crop cultivation.

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