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Weed control by pyrazosulfuron-ethyl and its influence on yield and economics of transplanted rice

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ABSTRACT

A field experiment was conducted on a silty clay loam soil at Palampur, Himachal Pradesh during *Kharif* 2016 and 2017 to assess pyrazosulfuron-ethyl as an alternative herbicide to manage weeds in transplanted rice. Ten treatments comprised of company released sample of pyrazosulfuron-ethyl at 10, 15, 20 and 30 g/ha was compared to its market sample at 10 and 15 g/ha, bispyribac- sodium at 20 and 40 g/ha, hand weeding twice and weedy check. Pyrazosulfuron-ethyl and bispyribac-sodium effectively reduced the biomass of *Echinochloa colona*, *Echinochloa crusgalli* and *Cyperus difformis*. These herbicides also suppressed the growth of *Ammannia baccifera*, but not to the extent as hand weeding twice. Pyrazosulfuron-ethyl curtailed *Eclipta alba*, but lower dose of bispyribac-sodium was not effective against it. In 2016, pyrazsulfuron-ethyl 20 g/ha gave significantly higher yield while in 2017, pyrazsulfuron-ethyl 30 g/ha gave significantly higher yield of rice over other weed control treatments. Every gram weed biomass increase per square metre caused 5.6 kg/ha yield reduction of transplanted rice. Samples of pyrazosulfuron-ethyl obtained directly from the industry had an edge over the market samples. Weed persistence index was found to be decreased and crop resistance index increased corresponding to increase of dose of pyrazosulfuron-ethyl and bispyribac-sodium. The minimum weed index was under company's pyrazosulfuron-ethyl at 20 g/ha followed by 15 g/ha, 30 g/ha and market's sample at 15 g/ha. Cost of weed control was 3.0 to 4.7% of the total cost with pyrazosulfuron-ethyl and 6.1 to 9.8% with bispyribac-sodium. Company procured pyrazosulfuron-ethyl at 15 and 20 g during 2016 and at 20 and 30 g/ha during 2017 had higher net returns and marginal benefit cost ratio (MBCR). Eighty per cent of applied pyrazosulfuron-ethyl got degraded within 5 days of its application. Residues of pyrazosulfuron-ethyl in grain and straw at the time of harvest were below detectable level (BDL) irrespective of treatments.

INTRODUCTION

More than half of rice cultivated in Himachal Pradesh is under low-land transplanted rice while the remaining is either under direct-dry-seeding (upland rice) or wet-seeding (sowing of sprouted seeds onto puddled soil) (Angiras *et al*. 2009). The average productivity of rice in the state (1.8 t/ha) is abysmally low as compared to national rice productivity (2.5 t/ ha). One of the major reasons for low productivity is the losses caused due to weeds (Rao *et al.* 2007). Weeds are generally managed either by herbicides or manually and mechanically. However manual weeding is becoming less common because of non-availability of labour at critical times and increased labour cost. Further manual weeding can be performed only when weeds have reached a sufficient size to be pulled out easily by hand. By that time, yield losses may have already occurred. It is, therefore, pertinent to have effective alternatives to manage them.

Use of herbicides has been found promising for managing weeds in different crops. Herbicides are the largest growing segment accounting for about 16% of total crop protection chemicals market (Sharma *et* *al*. 2017). Of a number of herbicides (butachlor, pendimethalin, bispyribac-sodium, cyhalofop-butyl *etc*.) developed and released by the private herbicide manufacturers for efficiently managing weeds in rice crop, pyrazosulfuron-ethyl, which is a sulfonylurea herbicide, was found giving very good control of grassy, broad-leaved and sedges in transplanted as well as direct-seeded rice (Ramesha *et al.* 2017, Saini *et al.* 2008). However, this herbicide need to be tested in elaborate research trials at different ecologies before it is recommended to farmers for adoption. Hence, the present study was undertaken in transplanted rice under mid hill conditions of Himachal Pradesh.

MATERIALS AND METHODS

The field experiment was carried out at Palampur (32^{o}62 N latitude, 76^{o}32 E longitude and 1290.8 m altitude) during *Kharif* 2016 and 2017. The area represents the mid hill sub-humid zone of Himachal Pradesh and is characterized by wet temperate climate. Agro climatically, the experimental site falls under sub-temperate humid zone of Himachal Pradesh, which is characterized by mild summers and cool winters. The area receives a high rainfall that ranges between 1800-2500 mm per annum, of which 80% is received during monsoon months from June to September.

Ten treatments comprising of a private company released samples of pyrazosulfuron-ethyl at 10, 15, 20 and 30 g/ha, market samples of pyrazosulfuron-ethyl at 10 and 15 g/ha, bispyribac-sodium 20 and 40 g/ha, hand weeding twice and weedy check were tested in randomized block design with three replications. Rice variety '*HPR 2143*' was transplanted on 7 July 2016 and 15 July 2017. The crop was fertilized with 90 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha through urea, single super phosphate and muriate of potash, respectively. The required quantity of half N and whole P_2O_5 and K_2O was drilled at sowing. The remaining half N was band placed at 55 DAS. The pyrazosulfuron-ethyl was sprayed 4 days after transplanting (DAT), during both the years, with power sprayer using 600 litres water/ha.

Weed biomass was estimated at 60 DAT, 90 DAT and at harvest by placing 25 × 25 cm quadrats in two spots at random in each plot. These samples were oven dried at a temperature of 70°C till constant weight. Yield attributes and yield were recorded at harvest. Yield was harvested from net plot. Cost of cultivation was worked out by taking together all costs on inputs and operations plus land revenue and interest on working capital. Gross revenue was computed based on the prevalent market prices of the main and by products. Net revenue was obtained by subtracting the cost of cultivation from gross revenue. Net returns per rupee invested was calculated by dividing net returns with cost of cultivation.

The data were subjected to statistical analysis by analysis of variance (ANOVA) for the randomized block design to test the significance of the overall differences among the treatments by the "F" test and conclusion was drawn at 5% probability level. Standard error of mean was calculated in each case. When the 'F' value from analysis of variance tables was found significant, the critical difference was computed to test the significance of the difference between the two treatments. The weed biomass was analysed after subjecting the original data to square root transformation *i.e.* ($\sqrt{x+0.5}$), and the treatments effects were compared using transformed means.

Impact assessment was carried out after Rana and Kumar (2014). Weed thresholds were worked out as per methods of Stone and Pedigo (1972) and Uygur and Mennan (1995). The soil, plant and grain samples were analyzed for the residues of pyrazosulfuron-ethyl. Pyrazosulfuron-ethyl was extracted with methanol and water. This mixture was subjected to shaking and filtration. The decanted solution was cleaned up in a bed of sodium sulphate using dichloromethane and NaCl. Then washings were concentrated in rotary vacuum evaporator after making the pH of the solution acidic (2.5) using 6N HCl. The residue was re-dissolved in acetonitrile and then subjected to analysis in HPLC equipped with Photo Diode Array Detector.

RESULTS AND DISCUSSION

Effect on weeds

The major weeds of the experimental field were *Echinochloa colona* (accumulated 23.1% and 16.3% of biomass during 2016 and 2017, respectively) and *Echinochloa crusgalli* (12.1% during 2016) among grasses, *Cyperus esculentus* (6.7% during 2017), *Cyperus difformis* (15.9 and 9.2%) and *Cyperus iria* (1.2% during 2016) among sedges and *Ammannia baccifera* (37.7 and 21.7%) and *Eclipta alba* (5.0% during 2017) among broad-leaf.

Weed control treatments brought about significant variation in the biomass of grasses, sedges and broad-leaved weeds (**Table 1**). All weed control treatments were significantly superior to weedy

Table 1. Effect of treatments on biomass (g/m^2) of grasses, sedges and broad-leaved weeds in transplanted rice at 90 DAT

Treatment	Dose (g/ha)	*E.colona*		*E.crusgalli*	*C. diffomis*		*C.iria*	*C.esculentus*	*A. baccifera*		*E.alba*	Total	
		2016	2017	2016	2016	2017	2016	2017	2016	2017	2017	2016	2017
Pyrazosulfuron-ethyl	10	3.3 (10.3)	0.7 (0.0)	2.5 (5.8)	3.1 (9.3)	2.4 (6.9)	1.7 (2.3)	2.5 (5.9)	4.3 (17.7)	4.5 (19.7)	0.7 (0.0)	7.0 (48.8)	6.4 (40.5)
Pyrazosulfuron-ethyl	15	3.3 (10.3)	2.0 (6.4)	2.7 (7.0)	3.2 (9.7)	2.4 (6.9)	1.6 (2.0)	2.1 (5.3)	4.2 (17.0)	3.5 (16.0)	0.7 (0.0)	7.0 (49.0)	5.2 (37.3)
Pyrazosulfuron-ethyl	20	3.0 (8.3)	2.0 (6.9)	2.6 (6.3)	3.1 (9.3)	2.3 (5.9)	1.3 (1.3)	1.9 (3.7)	3.5 (11.7)	3.7 (18.1)	0.7 (0.0)	6.3 (39.0)	5.5 (34.7)
Pyrazosulfuron-ethyl	30	2.7 (7.0)	0.7 (0.0)	2.6 (6.7)	2.3 (4.7)	2.3 (5.9)	0.7 (0.0)	1.9 (3.7)	3.3 (10.3)	3.4 (14.4)	0.7 (0.0)	5.6 (30.7)	4.8 (24.0)
Pyrazosulfuron-ethyl (market sample)	10	3.1 (9.0)	0.7 (0.0)	2.5 (6.1)	3.2 (10.0)	2.6 (8.5)	1.8 (2.7)	2.4 (5.3)	4.3 (17.7)	4.4 (19.2)	0.7 (0.0)	7.0 (48.8)	5.9 (34.7)
Pyrazosulfuron-ethyl (market sample)	15	3.1 (9.0)	0.7 (0.0)	2.5 (6.1)	3.1 (9.0	2.6 (8.5)	1.7 (2.3)	1.8 (3.2)	4.1 (16.3)	4.5 (20.3)	0.7 (0.0)	6.8 (46.4)	6.2 (39.5)
Bispyribac-sodium	20	3.0 (8.3)	0.7 (0.0)	2.5 (6.0)	2.8 (7.3)	2.7 (9.1)	1.5 (1.7)	1.9 (4.3)	3.9 (15.0)	3.6 (17.1)	1.8 (4.8)	6.4 (40.7)	6.3 (40.5)
Bispyribac-sodium	40	2.5 (6.0)	0.7 (0.0)	2.3 (5.1)	2.3 (4.7)	1.6 (3.7)	0.7 (0.0)	1.8 (3.7)	3.3 (10.7)	3.3 (14.4)	0.7 (0.0)	5.3 (27.4)	4.7 (21.9)
Hand weeding twice		1.7 (3.0)	0.7 (0.0)	1.7 (3.0)	1.9 (3.3)	1.3 (2.1)	0.7 (0.0)	1.8 (3.2)	2.3 (6.7)	2.7 (9.1)	1.7 (4.3)	3.9 (17.0)	4.1 (18.7)
Weedy check		4.9 (24.3)	4.0 (20.8)	3.6 (12.7)	4.1 (16.7)	3.0 (11.9)	1.3 (1.3)	3.0 (8.5)	6.3 (39.7)	5.3 (27.7)	2.4 (6.4)	10.2 (105.3)	11.1 (127.5)
LSD (p=0.05)		0.9	NS	0.9	0.5	1.0	0.5	1.8	1.2	1.1	1.1	1.2	2.1

Figures in parentheses are original value

check in curtailing the biomass of grasses, *viz. E. colona* during both the years and *E. crusgalli* during 2016. Hand weeding twice resulted in significantly lower density of all categories of weeds. All weed control treatments controlled *C. difformis* effectively during 2016. However, trends with respect to *C. iria* or *C. esculentus* were not conspicuous. Herbicides pyrazosulfuron-ethyl and bispyribac-sodium also suppressed the growth of *A. baccifera,* but not to the extent as hand weeding. Pyrazosulfuron-ethyl has effectively curtailed *E. alba*, but the lower dose of bispyribac-sodium was ineffective. Hand weeding also was not effective against *E. alba*.

Due to superior reduction of one or the other species, both pyrazosulfuron-ethyl and bispyribac sodium were superior to weedy check in curtailing total weed biomass. Control of weeds increased with increase in the dose of pyrazosulfuron-ethyl, but differences due to doses were not significant as reported by Ramesha *et al.* (2017). Pyrazosulfuron-ethyl gave control of weeds comparable to that with bispyribac-sodium. Manual weeding was better in effectiveness than herbicides except higher doses of pyrazosulfuron-ethyl or bispyribac-sodium during 2017. The effective control of grasses, sedges and broad-leaved weeds with pyrazosulfuron-ethyl (Ramesha *et al.* 2017, Saini *et al.* 2008) and bispyribac-sodium (Kumar and Rana 2013, Kumar *et al.* 2013) in rice has been reported.

Effect on crop

Weed control treatments resulted in significant variation in yield attributes and grain yield of rice (**Table 2**). Due to effective control of weeds, all treatments gave significantly higher yield attributes, *viz.* effective tillers and grains/panicle and yield of transplanted rice over the weedy check. Hand weeding twice (3.25 t/ha) had significantly higher yield at par with other herbicide treatments. Samples of pyrazosulfuron-ethyl obtained directly from the industry had an edge over the market samples. The increase in yield attributes and yield due to effective control of weeds with pyrazosulfuron-ethyl (Ramesha *et al.* 2017, Saini *et al.* 2008) and bispyribac-sodium (Kumar and Rana 2013, Kumar *et al.* 2013) in rice has been reported earlier also. The linear relationship between weed biomass (x) and yield (Y) of transplanted rice is given here as under;

Weed biomass

$Y = 2516 - 5.6x$ ($R^2 = 0.495$)................ (1)

Equation 1 explain over 50% of the variation in transplanted rice yield due to biomass of weeds, could be explained by this regression equation. With every gram weed biomass increase per square metre, the transplanted rice yield was expected to reduce by 5.6 kg/ha.

Table 2. Effect of treatments on yield attributes and yield of rice in 2016 and 2017

Treatment	Dose (g/ha)	Effective tillers (no./m²)		Grains/panicle		1000-grain weight (g)		Rice grain yield (t/ha)	
		2016	2017	2016	2017	2016	2017	2016	2017
Pyrazosulfuron-ethyl	10	330.0	396.0	96.0	94.7	21.7	22.3	1.13	2.96
Pyrazosulfuron-ethyl	15	335.0	407.0	97.3	97.7	23.3	23.7	1.94	3.02
Pyrazosulfuron-ethyl	20	354.2	451.0	99.7	95.7	22.3	23.7	2.00	3.13
Pyrazosulfuron-ethyl	30	346.7	473.0	99.7	99.3	22.3	23.7	1.52	3.19
Pyrazosulfuron-ethyl (market sample)	10	340.0	396.0	99.0	99.0	22.3	23.0	1.63	2.96
Pyrazosulfuron-ethyl (market sample)	15	340.0	407.0	97.3	100.7	21.7	23.0	1.68	2.99
Bispyribac-sodium	20	345.0	385.0	99.7	98.0	22.0	22.7	1.61	2.96
Bispyribac-sodium	40	355.0	451.0	100.0	98.7	22.7	24.0	1.18	3.16
Hand weeding twice	-	360.0	473.0	100.7	101.0	23.0	23.7	1.41	3.25
Weedy check	-	298.3	385.0	88.0	86.7	21.0	22.3	0.93	2.56
LSD (p=0.05)		42.0	52.6	8.5	8.2	NS	NS	0.3	0.3

Table 3. Economic thresholds and impact assessment indices under different treatments (mean of two years)

Treatment	Dose (g /ha)	Gt	Et		WCI	WPI	CRI	WMI	AMI	TEI	WI	W_i
			S&P	U&M								
Pyrazosulfuron-ethyl	10	48	8.5	2.8	61.7	0.60	2.99	1.84	0.84	0.35	12.1	39.0
Pyrazosulfuron-ethyl	15	55	9.8	2.7	63.0	0.61	3.93	2.18	1.18	1.01	-6.4	37.6
Pyrazosulfuron-ethyl	20	62	11.0	2.9	68.4	0.59	4.77	2.08	1.08	1.34	-10.3	34.8
Pyrazosulfuron-ethyl	30	76	13.5	3.8	76.5	0.50	5.72	1.71	0.71	1.31	-1.2	32.0
Pyrazosulfuron-ethyl (market sample)	10	48	8.5	2.4	64.2	0.51	3.69	1.98	0.98	0.76	1.5	41.4
Pyrazosulfuron-ethyl (market sample)	15	55	9.8	2.9	63.1	0.61	3.71	2.05	1.05	0.81	-0.4	37.8
Bispyribac-sodium	20	100	17.8	6.3	60.8	0.65	3.40	2.09	1.09	0.69	1.7	37.6
Bispyribac-sodium	40	167	29.6	9.3	78.8	0.45	5.73	1.53	0.53	0.97	6.8	32.1
Hand weeding twice	-	595	105.7	30.2	84.7	1.05	8.58	1.53	0.53	1.90	0.0	12.8
Weedy check	-	0	0.0	0.0	0.0	1.00	1.00	-	-	0.00	22.6	50.0

Gt, gain threshold, Et, economic threshold; S&P, after Stone and Pedigo; UM, after Uygur and Mennan; WCI, Weed control index (%); WPI, Weed persistence index; CRI, Crop resistance index; WMI, Weed management index; AMI, Agronomic management index; TEI, Treatment efficiency index; WI, Weed index; W_i , Weed intensity

Economic threshold

The economic threshold levels *i.e.* g/m² with the weed management practices varied between 8.5–105.7 g/m² when determined by Stone and Pedigo (1972) and 2.4 to 30.2 g/m² by Uygur and Mennan (1995) (**Table 3**). It is indicated that any increase in cost of weed control would lead to higher values of economic threshold, whereas an increase in price of crop produce would result in lowering the economic threshold. Hand weeding had higher values of economic threshold than the herbicidal treatments due to higher wages. Herbicidal treatments had lower application cost and thus had lower values of economic threshold. Among the treatments, market sample of pyrazosulfuron-ethyl at 10 g/ha had lowest values of economic threshold under both the methods of determination.

Impact assessment

Weed control index (WCI) increased with increase in dose of herbicides (**Table 3**). However, hand weeding treatment had higher weed control index due to frequent removal by hands followed by bispyribac-sodium at 40 g/ha and company sample of pyrazosulfuron-ethyl at 30 g/ha. All herbicide treatments had lower weed persistence index (WPI) than manual weeding. Weed persistence index was found to decrease as the dose of pyrazosulfuron-ethyl or bispyribac sodium increased. The crop resistance index (CRI) increased as the dose of each of pyrazosulfuron-ethyl and bispyribac-sodium increased. However, hand weeding had more crop resistance index (8.58) than all herbicidal treatments due to more weed control index.

Company sample of pyrazosulfuron-ethyl at 15 g/ha had highest weed management index followed by bispyribac-sodium at 20 g/ha, company sample of pyrazosulfuron-ethyl 20 g/ha and market sample of pyrazosulfuron-ethyl at 15 g/ha. Treatment efficiency index (TEI), which indicates weed killing potential and phytotoxicity on the crop, was higher under manual weeding followed by company's

Table 4. The cost of weed control, cost of cultivation (COC) and MBCR as influenced by weed control treatments

Treatment	Dose (g/ha)	Cost of weed control (`/ha)	Gross returns ($x10^3$ `/ha)		COC ($x10^3$ `/ha)		Gross return over weedy check ($x10^3$ `/ha)		Cost of weed control ($x10^3$ `/ha)		Net return due to weed control ($x10^3$ `/ha)		MBCR	
			2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Pyrazosulfuron-ethyl	10	960	32.2	72.7	29.9	33.2	5.8	9.2	1.3	1.6	4.5	7.6	3.40	4.71
Pyrazosulfuron-ethyl	15	1100	55.2	74.2	31.2	33.4	28.8	10.7	2.7	1.9	26.1	8.8	9.60	4.76
Pyrazosulfuron-ethyl	20	1240	57.0	76.9	31.5	33.7	30.6	13.5	3.0	2.2	27.6	11.3	9.34	5.18
Pyrazosulfuron-ethyl	30	1520	43.3	78.3	31.0	34.1	16.9	14.9	2.5	2.6	14.4	12.3	5.73	4.78
Pyrazosulfuron-ethyl (market sample)	10	960	46.3	72.6	30.6	33.2	19.9	9.2	2.1	1.6	17.8	7.5	8.54	4.65
Pyrazosulfuron-ethyl (market sample)	15	1100	48.0	73.9	30.9	33.3	21.6	10.4	2.3	1.8	19.2	8.6	8.28	4.75
Bispyribac-sodium	20	2008	46.0	73.1	31.7	34.3	19.6	9.7	3.2	2.7	16.4	6.9	5.17	2.55
Bispyribac-sodium	40	3336	33.6	77.6	32.4	36.0	7.2	14.2	3.9	4.4	3.3	9.7	0.85	2.20
Hand weeding twice	-	11900	40.1	79.6	41.8	45.1	13.7	16.2	13.2	13.6	0.5	2.6	0.04	0.19
Weedy check	-	0	26.4	63.4	28.5	31.5	-	-	-	-	-	-	-	0
LSD (p=0.05)			8.2	5.8	0.4	0.4	-		-	-	-	-	-	-

Table 5. Residues (µg/g) of pyrazosulfuron-ethyl in soil (*Kharif* 2017)

Treatment	Days after herbicide application						
	0	1	3	5	7	10	Harvest
Pyrazosulfuron-ethyl 10 g/ha (3 DAT)	0.179	0.120	0.079	0.046	BDL	BDL	BDL
Pyrazosulfuron-ethyl 15 g/ha (3 DAT)	0.194	0.131	0.107	0.056	BDL	BDL	BDL
Pyrazosulfuron-ethyl 20 g/ha (3 DAT)	0.242	0.148	0.114	0.061	BDL	BDL	BDL
Pyrazosulfuron-ethyl 30 g/ha (3 DAT)	0.297	0.191	0.127	0.069	BDL	BDL	BDL

BDL: Below Detectable level

pyrazosulfuron-ethyl 20 g/ha and 30 g/ha. Weed index (WI) is the measure of the efficiency of a treatment relative to weed free (hand weeding in the present case) indirectly indicating per cent yield reduction. It was highest under weed free. The value indicating 22.6% loss in grain yield of rice due to uncontrolled growth of weeds. The minimum weed index was under company's pyrazosulfuron-ethyl at 20 g/ha followed by 15 g/ha, 30 g/ha and market's sample at 15 g/ha. Hand weeding had the lowest weed intensity and weedy check had the highest.

Cost of weed control was 3.0 to 4.7% of the total cost due to pyrazosulfuron-ethyl and 6.1 to 9.8% with bispyribac-sodium. While that with hand weeding, weed control component had a major share of 27.4% of the total cost of production indicating that controlling weeds with manual methods is a costly proposition. Company procured pyrazo-sulfuron-ethyl at 15-20 g/ha during the first year and at 15-30 g/ha during second year, bispyribac-sodium 20-40 g/ha and hand weeding all during the second year resulted in higher gross returns due to weed control. But due to higher cost of labour, hand weeding resulted in lower net returns over weedy check than all the herbicidal treatments. Company procured pyrazosulfuron at 15-20 g during 2016 and at 20-30 g/ha during 2017 had higher net returns and marginal benefit cost ratio (MBCR).

Residual effects

A progressive decline in pyrazosulfuron-ethyl residue content in soil was observed with advancement of crop growth. Nearly 80% of applied pyrazosulfuron-ethyl got degraded within 5 days of its application and it was found below detectable level on 7th day and at harvest also (**Table 5**). Janaki *et al.* (2015) categorized pyrazosulfuron-ethyl under the herbicides those persist for 1-3 months. There was great influence of different doses of pyrazosulfuron-ethyl on the population of total bacteria, fungi and actinomycetes initially after 3 days of its application (6 DAT) (Kumar *et al.* 2018). Pyrazosulfuron-ethyl at 30 g/ha resulted in maximum reduction of 20.86, 26.39 and 14.12%, respectively, in bacterial, fungal and actionmycetes population. The population of microorganisms under observation was recovered from herbicide shock on 15 days after their spray. Residues of pyrazosulfuron-ethyl in grain and straw at the time of harvest were below detectable level irrespective of treatments.

The findings of the present investigation clearly indicated the effectiveness of pyrazosulfuron-ethyl as good as the standard herbicide bispyribac-sodium in reducing the biomass of weeds and increasing yield attributes and yield of rice.

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Entrapped pre-emergence oxadiargyl on growth and yield of rice under various agro-ecosystems

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ABSTRACT

Field experiments were carried out in two locations, *viz*. Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai and ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman and Nicobar Islands during *Kharif*, 2016 and 2017 respectively to study the effect of entrapped pre-emergence oxadiargyl herbicide on the growth and yield of rice under various agro ecosystems. Weed control measures significantly reduced the density and dry weight of weeds in both the ecosystems. In mainland ecosystem, at 20 DAT, the highest reduction in weed density (61.8%) was noticed with the application of oxadiargyl encapsulated with starch which was comparable with the application of butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT (60.8%). Whereas, under island ecosystem, the lowest total weed density (78.2%) was observed with the application of oxadiargyl loaded in zeolite which entrapped herbicides have increased sorption and decreased the dissipation of herbicide in soil which helps to release herbicide slowly through entire season for effective weed control. Application of butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT recorded significantly higher number of productive tillers/m^2 followed by the application of oxadiargyl loading with zeolite on 3 DAT. Weed free check has recorded significantly higher grain and straw yield in both ecosystems. The increase in grain yield with weed control treatment was ranged from 1.22 to 2.97 t/ha and 1.07 to 3.15 t/ha in main and island ecosystem, respectively compared to weedy check. The highest straw yield of 59.3 and 72.4% was recorded under weed free check as compared to weedy check in main and island ecosystem, respectively.

INTRODUCTION

Rice is the stable food crop and extensively grown cereal in more than hundred countries in the world. Asian countries produced and consumed 90 per cent of rice and it supplies 50 to 80% calories of energy. In India, rice occupies an area of 43.99 mha with production and productivity of 106.69 mt and 2.43 t/ha, respectively. In Tamil Nadu and Andaman Nicobar Islands the rice production is 6.40 and 0.013 m t from an area of 1.85 mha and 6400 ha with productivity of 3.47 and 2.05 t/ha, respectively (Indiastat 2018). Intensification of agriculture has provoked the complications of biotic stresses including insects, diseases and weeds on crops including rice. The world population is estimated to increase by 9 to11 billion by the year 2025 out of which 4.3 billion will be dependent on rice for their basic food. Agronomists are having great challenges to meet the food demands of the growing population and to achieve food security in the country, the present production levels need to be increased by two million tonnes every year.

Weeds are intense competition with rice crop for natural resources during the entire growth period, causing significant yield losses. Manual hand weeding is quite effective, but laborious and at earlier stages not easy due to morphologically weeds are similar to rice seedling (Rahman *et al.* 2012) which resulted time consuming and high cost. Shortage of agricultural labourers and increased wages rate, declining interest among farmers on agriculture-based occupation and raise of input cost caused rice farming less remunerative. In general, farmers are applying premergence herbicide which fails to control late emerging and diverse weed flora in rice. Encapsulated herbicides are expected to control the targeted weed species without affecting non-targeted plants and retained in soil throughout growing season which reduce late emerging weeds and not leaving herbicide residues at end of the cropping season (Bommayasamy *et al.* 2018). Therefore, the present study was carried out with the entrapped pre-emergence oxadiargyl herbicide on weed control and growth and yield of rice crop under various agro ecosystems.

MATERIALS AND METHODS

Field experiments were conducted in two locations, *viz*. Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai and ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman and Nicobar Islands during *Kharif*, 2016 and 2017 respectively to study the effect of entrapped pre-emergence oxadiargyl on growth and yield of rice under various agro ecosystems. The experimental sites were geographically located in the Western agro-climatic zone of Tamil Nadu and Islands agro climatic zones of India at $9^0$54'and $11^0$38' N latitude and $78^0$54' and $92^0$39' East longitude at an altitude of 147 m and 15 m above MSL, respectively. The soils of the experimental plots were sandy clay loam and clay loam with a pH of 6.9 to 7.3 and EC of 0.30 to 0.34, dS/m in texture with medium organic carbon (0.30 to 0.38%) status, low available nitrogen (246 to 263 kg/ha), medium in available phosphorus (16.1 to 19.5 kg/ha) and medium to high in available potassium (249 to 284 kg/ha), respectively.

The experiment was laid out in randomized block design with eight treatments and replicated thrice. Weed control treatments, *viz*. oxadiargyl (100 g/ha) loaded with 1:1 ratio of biochar or zeolite (100 g of zeolite/biochar was taken and added 1000 ml of 10% oxadiargyl and stirred it for 15 min in magnetic stirrer and suspension was allowed to dry for overnight which enables oxadiargyl to adsorb on the zeolite/biochar surface) applied at 3 days after transplanting (DAT), encapsulated oxadiargyl (100 g/ha) with starch or water soluble polymer (water soluble polymers like poly allylamine hydrochloride (PAH) and sodium poly styrene sulfonate (PSS) weighed each 20 mg was added to 20 ml 03-05 NaCl solution in separate beakers and dissolved it completely and pH was adjusted to neutral level. PAH solution was added to oxadiargyl and suspension was gently stirred in magnetic stirrer for 15 min followed by centrifuged at 1000 rpm for 15 min then rinsed three times with NaCl to remove the unbounded particles. The same procedure was repeated with oppositely charged polyelectrolyte (PSS). Then the suspension was centrifuged and allowed to dry for overnight), oxadiargyl alone at the rate of 100 g/ha, butachlor at the rate of 1.25 kg/ha applied on 3 DAT *fb* hand weeding on 40 DAT, weed free check and weedy check. The recommended dose of fertilizer (150: 50: 50 kg N: P_2O_5: K_2O /ha) was applied through urea, single super phosphate and muriate of potash. Nitrogen was applied in four splits at 10 DAT, active tiller, panicle initiation and flowering stages while 100% phosphorus and 50% potassium were applied as basal. Remaining 50% potassium was applied at panicle initiation stage. The paddy variety ***TKM-13*** with 130 days duration was used for the study. Seedling with age of 30 days old were transplanted on August, 2016 and July 30, 2017 with a spacing of 20 x 10 cm. The plots were irrigated to 2.5 cm depth of water upto establishment, thereafter cyclic submergence of 5 cm was continued thought the crop period. Need based plant protection measures were given whenever the incidences (leaf folder) more than economic threshold level. All other recommended package of practices was adopted as per the schedule. The data was statistically analyzed by following the method of Gomez and Gomez (1984). The data pertaining to weeds were transformed to square root of $\sqrt{x+2}$ and analysed as suggested by Snedecor and Cochran (1967).

RESULTS AND DISCUSSION

Effect on weeds

The dominant occurrence of weed species in rice could probably be due to the ecological adaptation of main and island ecosystems. Among the weeds *Echinochloa colonum*, *Leptochloa chinensis, Panicum flavidum* and *Cynodon dectylon* under grass, *Cyperus rotundus, Fimbristylis miliacea* and *Cyperus difformis* under sedges and *Eclipta alba, Ammannia baccifera, Convolvulus arvensis, Aeschynomene indica* and *Bergia capensis* under broad-leaved weeds were observed thought the period of experiment under mainland ecosystem. Whereas in Island ecosystem, the weeds, *viz*. *Echinochloa colonum, Cynodon dectylon* and *Setaria glauca* among grasses, *Cyperus haspan, Cyperus iria, Cyperus eragrostis, Cyperus difformis*, and *Fimbristylis miliacea* among sedges and *Sphenoclea zeylanica, Ammannia baccifera,* and *Bergia capensis* among BLW were observed during the entire crop growth season.

Weed control measures significantly reduced the density and dry weight of weeds in both the ecosystems (**Table 1**). In mainland ecosystem, at 20

Table 1. Effect of oxadiargyl encapsulated/loaded herbicide formulations on total weed density and total weed dry weight of rice under different ecosystem

Treatment	Mainland ecosystem				Island ecosystem			
	Total weed density (no./m^2)		Total weed dry weight (g/m^2)		Total weed density (no./m^2)		Total weed dry weight (g/m^2)	
	20 DAT	40 DAT	20 DAT	40 DAT	20 DAT	40 DAT	20 DAT	40 DAT
Oxadiargyl loaded with biochar on 3 DAT	7.43(53.3)	9.63(91.3)	3.45(9.92)	4.92(22.2)	5.86(32.3)	8.16(64.7)	2.95(6.7)	5.42(27.4)
Oxadiargyl loaded with zeolite on 3 DAT	7.02(47.3)	8.96(78.3)	3.41(9.62)	4.64(19.6)	5.48(28.0)	7.59(55.7)	2.30(3.3)	5.27(25.8)
Oxadiargyl encapsulated with starch on 3 DAT	6.29(37.7)	10.1(100.7)	3.60(11.0)	4.94(22.6)	6.43(39.3)	7.95(61.3)	2.98(6.9)	5.51(28.5)
Oxadiargyl encapsulated with water soluble polymer on 3 DAT	8.21(65.3)	10.3(105.3)	3.79(12.3)	4.77(21.3)	6.19(36.3)	8.24(66.3)	2.90(6.4)	5.81(31.8)
Oxadiargyl at 100 g/ha on 3 DAT	8.81(75.7)	11.1(120.7)	3.84(12.8)	5.28(25.8)	6.85(45.0)	9.47(88.0)	3.35(9.3)	5.93(33.2)
Butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT	6.36(38.7)	7.83(59.3)	3.66(11.4)	4.47(18.0)	9.48(88.0)	7.87(60.0)	4.22(15.8)	5.17(24.8)
Weed free check	1.41(0)	1.41(0)	1.41(0)	1.41(0)	1.41(0)	1.41(0)	1.41(0)	1.41(0)
Weedy check	10.0(98.7)	13.1(170.7)	5.89(32.8)	7.49(54.2)	11.4(128.3)	13.4(178.3)	6.79(44.2)	8.91(77.8)
LSD (p=0.05)	0.70	0.82	0.32	0.60	0.72	0.94	0.33	0.66

Original figures in parentheses were subjected to square root $\sqrt{x+2}$ transformation before statistical analysis, DAT: Days after transplanting

DAT, the highest reduction in weed density (61.8%) was noticed with application of oxadiargyl encapsulated with starch which was comparable with application of application of butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT (60.8%), application of oxadiargyl loaded in zeolite on 3 DAT (52.0%) and application of oxadiargyl loaded in biochar on 3 DAT (45.9%). Whereas, under island ecosystem, the lowest total weed density of 78.2% was observed with the application of oxadiargyl loaded in zeolite. It was on par with the application of oxadiargyl loaded in biochar. This might be due to higher adsorption of herbicide molecules in zeolite and biochar which released the active ingredients slowly and reduced leaching loss of herbicide and affects nutrient uptake by weeds under island ecosystem. Similar findings were reported by Bommayasamy *et al.* (2018). At 40 DAT, in mainland ecosystem, the highest reduction in weed density of 54.1, 46.6 % and weed dry weight of 63.7, 66.8% were observed with application of oxadiargyl loaded in zeolite and application of oxadiargyl loaded in biochar, respectively. Whereas, under island ecosystem, the lowest total weed density was recorded with the application of oxadiargyl loaded in zeolite followed by oxadiargyl encapsulated with starch and these treatments were on par with each other. Chinnamuthu *et al.* (2007) reported that smart delivery of herbicide will be more useful to exhaust the weed seed bank which is responsible for the weeds causing one hundred percentage crops loss, is a great accomplishment for the farming community.

Effect on crop growth

Weed control treatment significantly influenced plant height at harvest stage of the crop (**Table 2**). Plant height at harvest stage ranged from 5.1 to 18.1% and 2.8 to 21.8% higher than weedy check in

Table 2. Effect of oxadiargyl encapsulated/loaded herbicide formulations on plant height, leaf area index (LAI), crop growth rate of rice under different ecosystem

Treatment	Mainland ecosystem				Island ecosystem			
	Plant height (cm)	LAI at flowering	CGR (g/m^2/d)		Plant height (cm)	LAI at flowering	CGR (g/m^2/d)	
			Tillering - flowering	Flowering - harvest			Tillering - flowering	Flowering - harvest
Oxadiargyl loaded with biochar on 3 DAT	90.2	5.50	14.8	13.6	106.1	5.78	18.8	12.5
Oxadiargyl loaded with zeolite on 3 DAT	92.1	5.80	16.0	13.6	112.2	6.09	18.6	12.0
Oxadiargyl encapsulated with starch on 3 DAT	89.8	5.44	14.7	15.5	105.1	5.72	17.0	11.0
Oxadiargyl encapsulated with water soluble polymer on 3 DAT	89.1	5.37	15.4	12.1	102.5	5.64	18.0	13.0
Oxadiargyl at 100 g/ha on 3 DAT	86.9	5.22	14.2	12.5	101.5	5.48	14.9	11.2
Butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT	93.9	5.86	15.2	14.3	114.7	6.15	19.3	15.4
Weed free check	97.7	5.95	17.5	16.6	119.9	6.25	21.1	18.0
Weedy check	82.7	5.02	13.6	11.6	98.7	5.20	10.4	9.2
LSD (p=0.05)	8.1	0.56	1.7	1.6	12.3	0.59	2.8	1.2

DAT: Days after transplanting; CGR: crop growth rate; LAI: leaf area index main and island ecosystem, respectively. During this stage, among the weed control treatments, the highest plant height was recorded with the application of butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT under both the ecosystems. Whereas, other weed control treatments were on par with one another. The lowest plant height was observed with weedy check under both the ecosystems. Severe weed competition for natural resources results in suppression of crop growth at all stages of competition. This finding was in line with observations of Payman and Singh (2008). In mainland ecosystem, weed control treatment showed significant effect on LAI at flowering stage (**Table 2**). Weed free check recorded significantly higher LAI. Application of butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT significantly recorded higher LAI and was on par with application of oxadiargyl loaded in zeolite on 3 DAT and application of oxadiargyl loaded in biochar on 3 DAT. The least LAI was registered with the weedy check treatment. Whereas, similar trend was observed under island ecosystem with varied LAI, except application of oxadiargyl loaded with biochar on 3 DAT. This might be due to higher leaf area at flowering stage enabled the increased source-sink relationship through higher photosynthetic area of rice crop. This is in conformity with the findings of Rajput *et al.* (2017).

In mainland ecosystem, at tillering to flowering stage, weed free check recorded the highest crop growth rate (CGR) value (28.1%) and it was on par with application of oxadiargyl loaded with zeolite on 3 DAT. From flowering to harvest stage, higher CGR value (33.6, 23.3, 17.4, 17.4%) was recorded with the application of oxadiargyl encapsulated with starch, butachlor at 1.25 kg/ha applied on 3 DAT *fb* hand weeding on 40 DAT, oxadiargyl loaded in zeolite and oxadiargyl loaded in biochar, respectively. In island ecosystem, weed free check registered high CGR of 55.1% than weedy check at tillering to flowering stage and this was closely on par with application of butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT, application of oxadiargyl loaded in biochar and application of oxadiargyl loaded in zeolite. Whereas, at flowering to harvest stage, application of butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT recorded significantly higher CGR. The next best treatment was application of oxadiargyl encapsulated with water soluble polymer on 3 DAT, oxadiargyl loaded in biochar on 3 DAT and application of oxadiargyl loaded in zeolite on 3 DAT. Similar findings were reported by Sopena *et al.* (2009) who have revealed that alachlor encapsulated in EC is more effective in comparison to the commercial formulation.

Effect on yield components and yield

Number of productive tillers exhibited significant variation owing to weed control treatments. A significant increase in productive tillers formation resulted with weed free check in both ecosystems. In mainland ecosystem, the number of productive tillers/m^2 due to weed control treatment ranged from 238 to 363 productive tillers/m^2. Application of butachlor at 1.25 kg/ ha on 3 DAT *fb* hand weeding on 40 DAT recorded significantly higher number of productive tillers/m^2 followed by application of oxadiargyl loaded in zeolite on 3 DAT and application of oxadiargyl loaded in biochar on 3 DAT and were comparable with each other. In island ecosystem, similar trend was observed in the number of productive tiller/m^2 except application of oxadiargyl loaded in biochar on 3 DAT. The lowest number of productive tillers/m^2 was registered with weedy check in both ecosystems. Effective control of weeds during early stages of crop might have resulted in better tiller production. This finding is in conformity with the results of Bhimwal and Pandey (2014). Weed control treatment manifested favourable influence on the number of filled grains/ panicle (**Table 3**). In mainland ecosystem, among the weed control treatments, application of oxadiargyl loaded in zeolite on 3 DAT and oxadiargyl loaded in biochar on 3 DAT registered 30.9 and 21.8% more number of filled grains/panicle respectively. In island ecosystem, similar trend was noticed in the number of filled grains/panicle except oxadiargyl loaded in biochar on 3 DAT. The lowest number of filled grains/ panicle was registered in the weedy check treatment. This might be due effective control of weed dry matter accumulation favoured higher nutrient uptake by crop results in the production of more of filled grains/panicle. Similar lines of findings on the productive tillers, filled grains/panicle were obtained by Ganie *et al.* (2014). The difference in 1000 grain weight was not significant due to weed control treatments in both the ecosystems.

The grain and straw yield were significantly influenced by various weed control treatments (**Table 3**). Weed free check recorded significantly higher grain and straw yield in both ecosystems. Increased grain yield with weed control treatment was ranged from 1.22 to 2.97 t/ha and 1.07 to 3.15 t/ha in main and island ecosystem, respectively compared to weedy check. Application of butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT significantly recorded higher grain yield and was on par with the application of oxadiargyl loaded in zeolite on 3 DAT. The next best treatment was application of oxadiargyl

Table 3. Effect of oxadiargyl encapsulated/loaded herbicide formulations on yield attributes and yield of rice under different ecosystem

Treatment	Mainland ecosystem					Island ecosystem				
	Productive tillers/m^2	Filled grains/ panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Productive tillers/m^2	Filled grains/ panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Oxadiargyl loaded with biochar on 3 DAT	308	184.8	14.2	4.83	7.51	343	170.3	14.8	5.46	7.83
Oxadiargyl loaded with zeolite on 3 DAT	312	195.3	14.3	5.06	7.64	347	181.3	14.9	5.65	7.63
Oxadiargyl encapsulated with starch on 3 DAT	307	176.4	14.0	4.74	7.47	328	168.5	14.8	4.90	7.39
Oxadiargyl encapsulated with water soluble polymer on 3 DAT	279	172.3	14.1	4.28	7.39	322	163.6	14.7	4.70	8.36
Oxadiargyl at 100 g/ha on 3 DAT	278	164.8	14.0	4.07	7.18	302	154.3	14.3	4.34	7.13
Butachlor at 1.25 kg/ha on 3 DAT *fb* hand weeding on 40 DAT	321	187.2	14.2	5.34	7.75	372	187.0	14.9	5.93	8.70
Weed free check	363	227.6	14.6	5.83	8.84	380	213.3	15.2	6.42	9.57
Weedy check	238	149.2	13.5	2.86	5.55	284	146.5	13.9	3.27	6.15
LSD (p=0.05)	40	30.4	NS	0.44	1.12	31	16.7	NS	0.60	0.73

DAT: Days after transplanting

loaded in biochar on 3 DAT and oxadiargyl encapsulated with starch on 3 DAT. However, these two treatments were comparable with each other. The weed free check recorded 59.3 and 72.4% higher straw yield as compared to weedy check in main and island ecosystem respectively.

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Weed and nitrogen management in direct-seeded rice

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Weed control efficiency

ABSTRACT

A field experiment was conducted during *Kharif* seasons of 2014, 2015 and 2016 with an objective to assess the feasibility of weed and nutrient management in direct-seeded rice. The experiment was laid out in a factorial RBD with eighteen treatment combinations including six weed management treatments, *viz.* pretilachlor, pendimethalin, pretilachlor followed by (*fb*) bispyribac-sodium, pendimethalin *fb* bispyribac-sodium, weed free and weedy check and three nitrogen (N) levels, *viz.* 80, 100 and 120 kg N/ha with three replications. Significantly lower weed biomass was recorded with weed free which [2 hand weedings (HW) at 20 and 40 days after seeding (DAS)] was at par with pendimethalin 1.0 kg/ha pre-emergence treatment (PE) *fb* bispyribac-sodium 0.04 kg/ha, post-emergence treatment (PoE). Similarly, the highest weed control efficiency (WCE, 73.0%) and the lowest weed index (WI) were also recorded with weed free treatment, followed by pendimethalin 1.0 kg/ha *fb* bispyribac sodium 0.04 kg/ha (WCE, 71.2%). Rice growth and yield attributes, *viz.* plant height, effective tillers, panicles length, grains/panicle were improved significantly under combine application of PE and PoE herbicides either pendimethalin 1.0 kg/ha or pretilachlor 0.75 kg/ha (PE) *fb* bispyribac 0.04 kg/ha (PoE) and weed free [2 HW at 20 and 40 DAS]. Further, weed free treatment as well as pendimethalin 1.0 kg/ha *fb* bispyribac 0.04 kg/ha were found equally effective and recorded significantly higher rice grain and straw yield and nutrient use efficiency (NUE) with higher net returns compared to rest of treatments. Application of 120 kg N/ha significantly increased the plant height, effective tillers/plant, panicle length, grain/panicle, grain and straw yield, N content and NUE % over rest of the treatments in all aspects of yield and yield attributes. It was concluded that 2 HW at 20 and 40 DAS or application of pendimethalin 1.0 kg/ha *fb* bispyribac-Na 0.04 kg/ha for weed control appeared to be a viable strategy along with 120 kg N/ha for achieving higher and profitable yield of direct-seeded rice.

INTRODUCTION

Direct-seeded rice (DSR) is becoming popular as it is cheaper alternative to transplanting, which avoids the puddling and maintain continuous moist soil condition. It has several advantages such as requirement of 35-57% less water and 67% less labour over transplanting rice. Apart from these, DSR requires less use of machine, and have lesser methane emissions (Chauhan *et al.* 2012). The productivity of the dry DSR is often reported to be lower, mainly due to problems associated with weeds. Unpuddled and aerated tillage is highly vulnerable to weeds, which emerge early than the crop when adequate moisture and nutrients are available, hence the later stage of crop growth was slow down and finally decreased the yields. The extent of yield reduction of rice due to weeds has been estimated up to 95% (Naresh *et al.* 2011), 46.0 to 63.1% (Choudhary and Dixit 2018). Manual and mechanical control measures were effective against weeds but shortage of labour during peak period and escalating of labour wages are making delayed and expensive weed control practices.

The use of herbicides is gaining popularity in rice culture due to their rapid effects and lower costs compared to traditional methods. Weeds usually grow faster than crop plants and thus absorb nutrient earlier resulting in lack of nutrients for growth of plant. Nitrogen plays an important role in achieving higher yield and governing the photosynthetic activity. It is important to increase nitrogen utilization efficiency in rice production system as per the requirement of crop plants through weed management as nitrogen fertilization has pronounced effect on the growth of weeds. Patel *et al.* (2011) reported that management of weed along with fertilizers decreased crop-weed competition and increased net income by reducing losses due to weeds, increasing fertilizer use efficiency and finally the grain yield. Hence, it is essential to identify effective method of controlling weeds along with the application of fertilizers for attaining higher crop yield. The present study was conducted to identify a suitable nutrient use efficient weed control method in dry direct-seeded rice in south Gujarat.

MATERIALS AND METHODS

The study was conducted at Instruction Farm, NM College of Agriculture, Navsari Agricultural University, Navsari during *Kharif* season of 2014, 2015 and 2016. The soil of experimental site belongs to *Vertisol*. The pH of saturated soil paste was 7.7 and total soluble salts were 0.80 dS/m. Organic matter, available nitrogen, phosphorus and potassium were 0.78%, 271, 42 and 463 kg/ha, respectively. A field vacated by sunhemp (*Crotalaria juncea* L.) crop was selected and previous field history reveals the presence of diversified weed flora.

The experiment was laid out in a factorial randomized block design with three replications. Total eighteen treatments combination comprised six treatments of weed management *i.e.* pendimethalin 1.0 kg/ha as pre-emergence application (PE), pretilaclor 0.75 kg/ha (PE) *fb* bispyribac-sodium salt 0.04 kg/ha as post-emergence application (PoE), pendimethalin 1.0 kg/ha (PE) followed by (*fb*) bispyribac-sodium salt 0.04 kg/ha (PoE), weed free [two hand weedings (HW) at 20 and 40 days after seeding (DAS)] and unweeded control, and three nitrogen levels *i.e.* 80, 100 and 120 kg N/ha. The net plot size was 4 × 5 m. The rice cultivar '*NAUR-1*' seed was soaked in water for 6 hours prior to sowing. The rice was sown in the second week of July with single row hand drill, using a seed rate of 50 kg/ha and maintaining 30 cm distance between crop rows.

Nitrogen fertilizer was applied as urea and phosphorus 30 kg P_2O_5/ha as single super phosphate. Half of the nitrogen and full dose of P were applied at the time of sowing. Remaining half of nitrogen was top dressed in two equal splits at tillering and panicle initiation, respectively. Pre-emergence herbicide was applied just after sowing and post-emergence herbicide was applied at 30 days after sowing as per the treatment. Herbicides were applied using a knapsack spray fitted with a flat-fan nozzle. Volume of spray (460 L/ha) was determined after calibration. For manual weeding, weeds were removed by hand pulling. A weedy check was maintained to compare herbicidal treatments. Data on weed dynamics (density and dry biomass) were recorded at 20, 40 and at harvest from two randomly selected quadrates (1 m^2) from each experimental unit. Weeds were clipped from ground surface, and dried in an oven at 70 ºC for 48 h for determining dry weed biomass. Data on rice yield attributes were recorded from 10 randomly selected plants taken from each net plot and computing their average. Productive tillers/m^2 were counted from two randomly selected sites from each net plot and averaged. Crop was harvested and tied into bundles in respective plots.

Each experimental plot was manually threshed to determine grain yield. Treatment wise economics were calculated by considering prevailing market price as follow; labour: ` 178/day; two hand weeding: ` 5340/ha; pretilachlor: ` 515/L; pendimethalin: ` 600/L; bispyribac-sodium salt: ` 3600/L; nitrogen (urea): ` 13.7/kg; phosphorus (SSP): ` 7.3/kg; paddy: ` 15/kg and paddy straw: ` 3/kg. The data collected were subjected to Fisher's analysis of variance technique using "MSTATC" statistical software at 0.05 probabilities to compare the differences among treatments' means.

RESULTS AND DISCUSSION

Effect on weeds

The major weed flora in the experimental field comprised of grasses, *Digitaria sanguinalis*, *Echinochloa crus-galli*, *Echinochloa colona*, *Panicum repens*; sedges, *Cyperus iria*, *Cyperus difformis*, *Fimbristylis miliacea* and broad-leaved weeds (BLW), *Portulaca oleracea*, *Ammania baccifera*, *Ludwigia paraviflora*, *Eclipta alba*, *Marsilea quadrifolium* and *Commelina benghalensis*. The composition of grasses, sedges and broad-leaf weeds in weedy check plot was 65.5, 2.0 and 32.5%, respectively.

Application of pretilachlor 0.75 kg/ha and pendimethalin 1.0 kg/ha PE alone or in sequential application with bispyribac-sodium 0.04 kg/ha (PoE) was the best in controlling grasses and broad-leaf weeds, but failed to exert their significant effect on sedges. The pre-emergence application of herbicides significantly reduced the total weed density during initial periods of crop growth. Significantly, minimum and maximum total weed density was recorded with pendimethalin 1.0 kg/ha PE and + bispyribac-sodium 0.04 kg/ha (PoE) and unweeded control, respectively. Similarly, weeds biomass was also significantly minimum with herbicidal application alone or in combination at 40 DAS and weed free compared to unweeded control treatments. However, at harvest, weed free treatment has recorded significantly lower weed biomass, being at par with pretilaclor 0.75 kg/

ha and pendimethalin 1.0 kg/ha followed by bispyribac-sodium 0.04 kg/ha, as PE herbicides kill first flush of weeds and PoE herbicides kill weeds in the critical period of crop weed competition. The results are in conformity with finding by Singh *et al.* (2016).

Significantly higher weed control efficiency and lower weed index were recorded with weed free treatment, followed by pendimethalin *fb* bispyribac-sodium and pretilachlor *fb* byspyribac-sodium. Unweeded check recorded maximum weed index and showed 71.2% yield loses of direct seeded rice. The findings were in conformity with those reported by Sunil *et al.* (2010).

The monocot, dicot weed population, were maximum with 120 kg N/ha and minimum with 80 kg N/ha. However, sedges weeds were unaffected by different N practice application rates. Increasing dose of N significantly increased the total weed density and biomass at 40 DAS and at harvest, which might be due to increased availability of nutrients for weed growth and development.

Effect on crop

Significantly, higher plant height (119 cm) was recorded under weed free (two HW at 20 and 40 DAS) treatment, being at par with pretilachlor 0.75 kg/ha or pendimethalin 1.0 kg/ha PE *fb* byspyribac-sodium salt 0.04 kg/ha PoE due to better control of weeds, reduced crop weed competition facilitating sufficient space, nutrients and light for better growth. Further, significantly the lowest plant height was recorded under treatment unweeded check. This might be due to severe competition by weeds for resources.

Significantly the highest plant height (116 cm) was recorded with application of nitrogen at 120 kg N/ha, while the lowest (103 cm) with 80 kg N/ha. The increase in plant height in response to application of N fertilizers is probably due to enhanced availability of nitrogen.

Yield and yield attributes

Application of pretilachlor 0.75 kg/ha or pendimethalin 1.0 kg/ha PE *fb* byspyribac-sodium 0.04 kg/ha PoE and weed free (two HW at 20 and 40 DAS) was found equally effective and recorded significantly, higher number of effective tillers/m^2, panicle length and grains/panicle at harvest. Maintaining high soil fertility status by way of controlling weeds and removing less plant nutrient through weeds might have modified yield attributes. Significantly, higher grain (2.35 t/ha) and straw (4.60 t/ha) yields of dry-DSR was recorded with weed free (two HW at 20 and 40 DAS) and found at par with application of pendimethalin 1.0 kg/ha *fb* byspyribac-sodium 0.04 kg/ha PoE (**Table 2**). The increase in grain yield under these treatments was due to the fact that the weed density and biomass remained suppressed during crop growth period, resulting in reduced weed competition, which provided better environment for proper development of growth characters, *viz.* plant height and number of tillers/m row length (mrl) and yield attributes, *viz.* number of panicles/mrl, panicle length and number of grains/ panicle, ultimately enhanced the grain yield of rice. Result also revealed that effective weed control in early stages of crop growth is essential for higher grain yield in direct-seeded rice crop. The results of present investigation were also in agreement with the findings supported by Sunil *et al.* (2010) and Joshi *et al.* (2015).

Table 1. Weed density, weed biomass, weed control efficiency (WCE) and weed index as influenced by weed and nitrogen management in dry direct-seeded rice (pooled over 3 year)

Treatment	Dose (kg/ha)	Weed density (no./m^2) at 40 DAS				Weed biomass		WCE (%)	Weed index (%)
		Grasses	Sedges	BLWs	Total	40 DAS (g/m^2)	At harvest (kg/ha)		
Weed management									
Pretilaclor PE	0.75	16.6(4.2)	2.0(1.7)	11.7(3.5)	30.2(5.6)	10.7	427	51.8	29.7
Pendimethalin PE	1.0	16.9(4.2)	2.2(1.7)	10.9(3.4)	30.0(5.5)	11.0	518	41.5	24.2
Pretilaclor PE *fb* bispyribac-sodium PoE	0.75, 0.04	16.9(4.2)	2.4(1.8)	12.7(3.7)	32.0(5.7)	11.5	281	68.3	12.1
Pendimethalin PE *fb* bispyribac-sodium PoE	1.0, 0.04	15.1(4.0)	2.2(1.8)	12.7(3.7)	30.0(5.5)	10.5	255	71.2	1.8
Weed free (2 HW at 20 & 40 DAS)	-	24.4(5.0)	2.1(1.8)	11.8(3.6)	38.3(6.2)	19.6	239	73.0	-
Unweeded control	-	66.4(8.2)	2.0(1.7)	33.0(5.8)	101.4(10.1)	32.6	886	-	71.2
LSD (p=0.05)		0.54	NS	0.56	0.57	1.14	92		
Nitrogen level									
80 kg N/ha		22.1(4.6)	1.9(1.7)	13.0(3.7)	37.0(6.0)	13.8	383	-	-
100 kg N/ha		25.6(4.9)	2.1(1.7)	15.2(3.9)	42.9(6.4)	15.6	434	-	-
120 kg N/ha		30.5(5.3)	2.4(1.8)	18.2(4.2)	51.1(6.9)	18.6	485	-	-
LSD (p=0.05)		0.38	NS	0.40	0.40	0.80	65	-	-

Figure in parentheses indicates transformed ($\sqrt{x+1}$) value and outside parentheses refereed to original value; DAS = Days after seeding

Table 2. Growth and yield attributes, yield, NUE (%), N content in grain and economics of dry direct-seeded rice as influenced by weed and nitrogen management (pooled over 3 year)

Treatment	Dose (kg/ha)	Plant height (cm)	Effective tillers (no./m^2)	Panicle length (cm)	Grains /panicle (no.)	Grain yield (t/ha)	Straw yield (t/ha)	NUE (%)	Grain N content (%)	Cost of cultivation (x10^3 `/ha)	Net returns (x10^3 `/ha)	B:C ratio
Weed management												
Pretilaclor PE	0.75	105	200	21.1	54.3	1.64	3.44	16.3	1.26	21.18	13.71	1.65
Pendimethalin PE	1.0	111	208	23.4	56.6	1.78	3.66	18.0	1.28	20.89	16.76	1.80
Pretilaclor PE *fb* Bispyribac sodium PoE	0.75, 0.04	115	238	25.3	70.0	2.03	4.14	20.6	1.36	26.93	15.97	1.59
Pendimethalin PE *fb* Bispyribac sodium PoE	1.0, 0.04	118	244	26.5	70.9	2.28	4.55	23.2	1.37	27.65	20.24	1.73
Weed free (2 HW at 20 and 40 DAS)	-	119	251	26.3	72.4	2.35	4.60	23.9	1.42	23.87	25.23	2.06
Unweeded control	-	91	123	19.1	42.6	0.64	1.99	6.60	1.22	18.53	-2.99	0.84
LSD (p=0.05)		5	14	1.3	9.4	0.10	0.10	1.10	0.09			
Nitrogen levels												
80 kg N/ha		103	188	22.1	53.3	1.60	3.35	16.7	1.27	19.04	15.10	1.79
100 kg N/ha		110	206	23.3	61.3	1.76	3.64	17.6	1.32	19.16	18.15	1.95
120 kg N/ha		116	237	25.5	67.7	2.00	4.19	20.1	1.38	19.29	23.26	2.21
LSD (p=0.05)		3	10	0.9	3.4	0.07	0.020	0.70	0.06			

The number of effective tillers/m^2, panicle length and grains/panicle increased gradually due to increasing level of N and significantly higher with 120 kg N/ha. These might be due to favorable root growth and higher mobility of N in soil solution and its absorption by plant root with higher N application. Enhanced application from 80 to 120 kg N/ha resulted in significant increase in grain and straw yield (**Table 2**) of DSR. Application of 120 kg N/ha produced significantly the highest grain (2.0 t/ha) and straw (4.19 t/ha) yield.

N content and nitrogen use efficiency percentage (NUE %)

Weed free treatment was found at par with pendimethalin *fb* bispyribac-sodium for NUE (23.9 and 23.2%, respectively); pendimethalin *fb* bispyribac-sodium and pretilaclor *fb* bispyribac-sodium for N content (1.42, 1.37 and 1.36, respectively) (**Table 2**). While, the lowest N content (1.26%) and NUE (16.3%) was rerecorded with unweeded control treatment. Further, higher dose of nitrogen *i.e.* 120 kg N/ha significantly improved NUE % and N content in rice grain.

Economics

Weed free recorded maximum net returns of ` 25235/ha and B:C ratio of 2.06 followed by pendimethalin *fb* byspyribac-Na with net returns of ` 20239/ha with B: C ratio of 1.73. Unweeded check recorded net loss of ` 2992/ha with B:C ratio of 0.84. Application of nitrogen 120 kg N/ha fetched maximum net returns of ` 23261/ha and B:C ratio of 2.21.

Two HW at 20 and 40 DAS were found effective to manage weeds in dry-DSR. Pre-emergence application of pendimethalin at 1.0 kg/ha PE *fb* bispyribac-sodium at 0.04 kg/ha PoE was found to be appropriate weed management strategy for use under labour scare condition. Application of nitrogen 120 kg N/ha gave higher and profitable rice yield.

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Management of complex weed flora in transplanted rice by herbicide rotation and green manuring

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ABSTRACT

A field study was conducted at Dr. Balasdaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (Maharashtra) during *Kharif* 2011 to 2014 to evaluate the effect of green manuring with *Sesbania rostrata* and different herbicide on complex weed flora in transplanted rice. The experimental field was infested with *Ludwigia octovalis*, *Cloem viscosa*, *Cyperus iria*, *Amaranthus sessils*, *Isachne globosa* and *Eriocaulon hexangularis*. Four year pooled data revealed that green manuring did not influence the dry matter of monocots and BLWs at all the stages of observation. Green manuring significantly influenced the grain and straw yields of rice and produced significantly higher grain and straw yields (3.86 grain and 3.87 straw t/ha) as compared to without green manuring. Pre-emergence application of pretilachlor-S 0.75 kg/ha at 3-7 DAT recorded the highest weed control efficiency (36.40% at 30 DAT and 48.18% at 50 DAT) and rice grain yield (3.54 t/ha).

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food of more than 60% of the world population and more than 70 % of the Indian population. In India, rice occupies an area of 43.39 mha with production and productivity of 104.32 million tons (mt) and 2.4 t/ha, respectively (Anonymous 2016. India should add 1.7 mt of additional rice every year to ensure national food security (Das and Chandra 2013). Though, India has the largest area under rice in the world but its productivity is very low. This might be due to several constraints. Among them weeds pose a major threat. Uncontrolled weed growth causes 33-45% reduction in grain yield of transplanted rice (Singh *et al.* 2007, Manhas *et al.* 2012). There is tremendous scope of incorporation of legume green manuring in rice because of its weed smothering efficiency. Therefore, the present investigation was carried out to study the influence of green manure and weed control measures in transplanted rice.

MATERIALS AND METHODS

A field experiment was conducted during 2011 to 2014 at Dr. Balasdaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (Maharashtra). The experimental site was located at west coast 250 m height from mean sea level having annual average rainfall 3500 mm with 95 to 100 rainy days throughout *Kharif* season.

The experiment was laid out in a strip-plot design with three replications. The two main plot treatment comprised of application of green manuring and without green manuring and four sub-plot treatments comprised of fixed herbicide (pretilachlor-S 0.75 kg/ha at 3-7 DAT), rotational herbicide (pyrazosulfuron 0.030 kg/ha at 8-10 DAT (I year), fenoxaprop -p-ethyl 0.056 kg/ha at 25-30 DAT (II year), oxadiargyl 0.100 kg/ha at 0-5 DAT (III year), weed free check [two hand weeding (HW)] at 20 and 40 DAT and weedy check.

The soil of the experimental plot was sandy clay loam in texture, acidic in pH and medium in organic carbon content. It was low in available nitrogen (282 kg/ha), medium in available phosphorus (10.8 kg/ha) and high in available potassium (236 kg/ha). The gross main plot size was 10 × 10 m. and net plot size 2.3 × 10 m. The seed of rice variety *'Ratnagiri-24'* was treated with thairum at the rate of 3 g/kg of seed used for sowing. Twenty one days old rice seedlings were transplanted in puddled field. The recommended dose of fertilizer (100:50:50 N, P_2O_5, and K_2O kg/ha) was applied to all the plots. Half dose of nitrogen and full dose of phosphorus and potassium was applied at the time of puddling while remaining half dose of nitrogen was applied at 30 DAT. The uniform representative samples of crop as well as weeds were randomly collected from each plot. Data were analyzed (pooled analysis) statistically by using standard methods of Panse and Sukhatme (1984). The significant differences between treatments were compared by critical difference at 5% level of probability. The data on weed density and biomass were subjected to square root transformation for comparison.

RESULTS AND DISCUSSION

The experimental field was comprised with major weed, *viz. Ludwigia octovalis, Cloem viscosa, Cyperus iria, Amaranthus sessils, Isachne globosa, Eriocaulon hexangularis, Cyperus rotundus, Eleusine indica, Echinochloa colona, Ischemum rugosum, Mimosa pudica, Physalis minima*, and *Celocia argentea.*

Weed density

Weed density of monocots and broad-leaved weeds in rice at 30 and 50 DAT did not influence significantly due to green manuring (**Table 1 and 2**). However, less number of weeds was observed in green manuring than without green manuring. These results are in line with the findings of Gnanavel and Kathiresan (2002) who reported that green manuring with *Sesbania aculeata* reduced the weed density and increased the weed control index in the succeeding rice crops. In rice-wheat cropping systems, inclusion of *Sesbania aculeata* in summer resulted in least grasses and sedges in the succeeding crops (Singh *et al.* 2008).

Weed control measures did not significantly influence density of monocots and BLWs at 30 DAS, except during 2014 (**Table 1**) and pooled results in respect of BLWs. Weed free check two hand weeding (HW) significantly reduced the weed density of monocots and BLWs over weedy check and application of rotational herbicide (pyrazo-sulfuron 0.030 kg/ha at 8-10 DAT (I year)**,** fenoxaprop -p-ethyl 0.056 kg/ha at 25-30 DAT (II year), oxadiargyl 0.100 kg/ha at 0-5 DAT (III year) but it was at par with application of pretilachlor-S herbicide during 2014.

Weed free check two hand weeding significantly reduced the density of monocots and BLWs, but it was at par with application of pretilachlor-S herbicide at 50 DAT (**Table 2**) and remained at par with rotational herbicide (pyrazosulfuron 0.030 kg/ha at 8-10 DAT (I year), fenoxaprop -p-ethyl 0.056 kg/ha at 25-30 DAT (II year), oxadiargyl 0.100 kg/ha at 0-5 DAT(III year). Higher weed control efficiency was observed in weed free check [two hand weeding (HW)] followed by application of pretilachlor-S herbicide. Duary *et al.* (2015) also reported similar results.

Table 1. Effects of green manuring and weed control measures on weed density in rice at 30 DAT (no./m^2) (four years pooled mean)

Treatment	Grasses and sedges					Broad-leaved weeds					Weed control efficiency				
	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled
Green manuring															
Green manuring	10.5	11.7	23.7	22.3	17.7	2.6	1.3	1.0	8.3	3.5					
	(3.04)	(3.28)	(4.65)	(4.72)	(4.20)	(1.48)	(1.08)	(0.94)	(2.87)	(1.96)					
Without green manuring	13.5	23.3	22.0	25.0	20.3	2.3	2.3	1.0	10.3	3.8					
	(3.45)	(4.31)	(4.27)	(5.01)	(4.49)	(1.29)	(1.43)	(1.01)	(3.22)	(2.06)					
LSD (p=0.05)	-	-		-	-	-	-	-	-	-					
	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)					
Weed control measure															
Fixed herbicide – pretilachlor-S (PE)	10.6	12.0	20.7	19.3	18.9	2.7	1.3	0	8.0	3.5	46.6	56.5	32.6	42.3	17.97
	(3.09)	(3.19)	(4.49)	(4.44)	(4.32)	(1.41)	(1.08)	(0.71)	(2.86)	(1.98)					
Rotational herbicide	13.0	18.7	26.7	22.0	21.7	2.7	2.0	0	9.3	3.3	37.4	32.6	13.0	33.82	8.20
	(3.12)	(4.00)	(4.84)	(4.66)	(4.63)	(1.27)	(1.31)	(0.71)	(3.08)	(1.93)					
Weed free check	4.0	11.3	17.3	16.7	13.2	0	1.3	0	5.3	2.7	84.0	58.7	43.5	53.53	42.02
	(1.64)	(3.29)	(4.09)	(4.13)	(3.67)	(0.71)	(1.08)	(0.71)	(2.39)	(1.76)					
Weedy check	20.3	28.0	26.7	32.7	22.2	4.6	2.7	4.0	14.7	5.2					
	(3.93)	(4.71)	(4.41)	(5.75)	(4.75)	(2.14)	(1.55)	(1.78)	(3.86)	(2.36)					
LSD (p=0.05)	-	-	-	4.4	-	-	-	-	3.9	1.5					
	(NS)	(NS)	(NS)	(0.44)	(NS)	(NS)	(NS)	(NS)	(0.64)	(0.37)					

Figures in parentheses indicate square root transformations $\sqrt{x+0.5}$; NS: Non-significant, Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations; PE: pre-emergence

Table 2. Effects of green manuring and weed control measures on weed density in rice at 50 DAT (no./m^2) (four years pooled mean)

Treatment	Grasses and sedges					Broad-leaved weeds					Weed control efficiency				
	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled
Green manuring															
Green manuring	18.80	5.00	26.67	29.33	24.28	0.02	3.00	8.33	22.33	8.42					
	(3.62)	(2.15)	(5.09)	(5.38)	(4.90)	(0.72)	(1.45)	(2.49)	(4.73)	(2.92)					
Without green manuring	39.83	8.33	44.00	28.33	25.79	1.34	4.00	7.33	19.67	8.08					
	(5.39)	(2.69)	(6.56)	(5.25)	(4.98)	(1.13)	(1.83)	(2.35)	(4.44)	(2.88)					
LSD (p=0.05)	(NS)	(NS)	(NS)	(NS)	(NS)	(0.29)	(NS)	(NS)	(NS)	(NS)					
Weed control measure															
Fixed herbicide – pretilachlor-S (PE)	23.32	7.33	36.00	22.00	23.00	1.33	2.67	8.67	20.00	6.34	53.4	37.5	16.2	40.6	38.5
	(3.95)	(2.58)	(5.88)	(4.70)	(4.72)	(1.18)	(1.41)	(2.73)	(4.49)	(2.57)					
Rotational herbicide	36.35	7.33	39.33	33.33	28.25	0.02	3.33	10.00	20.67	8.50	31.3	33.4	7.5	23.6	23.0
	(5.25)	(2.44)	(6.17)	(5.80)	(5.30)	(0.72)	(1.68)	(2.95)	(4.56)	(2.98)					
Weed free check	6.01	4.67	24.67	17.33	13.17	0.02	1.33	0.67	15.33	6.17	88.6	62.5	52.4	53.8	59.5
	(1.89)	(2.02)	(4.91)	(4.20)	(3.68)	(0.72)	(1.18)	(0.94)	(3.96)	(2.55)					
Weedy check	51.58	9.33	41.33	42.67	35.73	1.34	6.67	12.00	28.00	12.00					
	(6.94)	(3.35)	(6.33)	(6.56)	(6.00)	(1.08)	(2.29)	(3.06)	(5.32)	(3.49)					
LSD (p=0.05)	(NS)	(NS)	(NS)	(0.72)	(1.05)	(NS)	(NS)	(NS)	(0.53)	(0.66)					

Figures in parentheses indicate square root transformations $\sqrt{x+0.5}$; NS: Non-significant, Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations; PE: pre-emergence

Table 3. Effects of green manuring and weed control measures on weed dry matter in rice at 30 DAT (no./m^2) (four years pooled mean)

Treatment	Grasses and sedges					Broad-leaved weeds					Weed control efficiency				
	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled
Green manuring															
Green manuring	3.99	5.10	3.36	4.54	4.76	2.34	0.70	0.04	2.17	1.56		-	-	-	-
	(1.83)	(2.19)	(1.77)	(2.24)	(2.27)	(1.30)	(0.95)	(0.73)	(1.62)	(1.37)					
Without green manuring	5.99	10.83	8.56	4.58	6.98	3.34	2.51	0.04	1.63	1.63		-	-	-	-
	(2.32)	(3.09)	(2.84)	(2.25)	(2.69)	(1.57)	(1.44)	(0.73)	(1.44)	(1.38)					
LSD (p=0.05)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)					
Weed control measure															
Fixed herbicide – pretilachlor-S (PE)	4.64	7.06	6.58	4.41	5.66	2.00	1.16	0.00	1.87	1.26	56.7	46.0	6.4	20.5	36.4
	(2.15)	(2.57)	(2.46)	(2.21)	(2.49)	(1.32)	(1.10)	(0.71)	(1.52)	(1.29)					
Rotational herbicid	7.30	9.46	6.65	4.67	7.05	2.01	1.52	0.00	1.25	1.79	39.2	27.9	5.4	25.1	18.7
	(2.72)	(3.10)	(2.38)	(2.27)	(2.78)	(1.19)	(1.11)	(0.71)	(1.39)	(1.48)					
Weed free check	0.02	3.43	3.72	3.94	5.00	0.02	0.64	0.00	1.03	0.46	99.7	73.3	47.1	37.1	49.8
	(0.72)	(1.79)	(1.98)	(2.11)	(2.30)	(0.72)	(0.94)	(0.71)	(1.23)	(0.96)					
Weedy check	7.99	11.91	6.89	5.23	8.00	7.33	3.32	0.14	2.67	2.88	-	-	-	-	-
	(2.72)	(3.12)	(2.40)	(2.39)	(2.98)	(2.52)	(1.97)	(0.80)	(1.77)	(1.78)					
LSD (p=0.05)	(NS)	(NS)	(NS)	(0.11)	(0.39)	(NS)	(NS)	(NS)	(0.21)	(0.51)					

Figures in parentheses indicate square root transformations $\sqrt{x+0.5}$; NS: Non-significant, Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations; PE: pre-emergence

Weed dry matter

Four year pooled data revealed that green manuring did not influence the dry matter of monocots and BLWs at all the stages of observation (**Table 3**). However, least weed dry matter was observed in green manuring than without green manuring. These results were in line with the findings of Mathew and Alexander (1995) who reported that intercropping with *Sesbania aculeata* and manual incorporation of the same at 35 DAS in semi-dry rice recorded the lowest weed dry matter compared with sole paddy crop. Similar results were recorded by Nalini *et al.* (2008).

Weed free check (two hand weeding) significantly reduced the weed dry matter of monocots and BLWs at 30 DAT (**Table 3**), however, it was at par with the use of application of pretilachlor-S herbicide during 2014 (**Table 4**) .Among the herbicides, pretilachlor-S reduced weed dry matter of monocots than application of rotational herbicide pyrazosulfuron 0.030 kg/ha at 8-10 DAT (I year)**,** fenoxaprop -p-ethyl 0.056 kg/ha at 25-30 DAT (II year)**,** oxadiargyl 0.100 kg/ha at 0-5 DAT (III year). However, dry matter of BLWs was not affected due to various weed control measures. Higher weed control efficiency was observed in weed

Table 4. Effects of green manuring and weed control measures on weed dry matter in rice at 50 DAT (no./m^2)

Treatment	Grasses and sedges					Broad-leaved weeds					Weed control efficiency				
	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled
Green manuring															
Green manuring	5.06	5.00	26.67	29.33	17.51	0.02	3.04	0.55	3.01	1.65		-	-	-	-
	(2.00)	(2.15)	(5.09)	(5.38)	(4.31)	(0.72)	(1.40)	(0.96)	(1.86)	(1.39)					
Without green manuring	12.40	8.33	44.00	28.33	25.79	2.68	5.71	0.49	2.57	2.86		-	-	-	-
	(3.06)	(2.69)	(6.56)	(5.25)	(4.98)	(1.35)	(1.99)	(0.95)	(1.74)	(1.67)					
LSD (p=0.05)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)	(NS)					
Weed control measure															
Fixed herbicide – pretilachlor-S (PE)	7.67	7.33	36.00	22.00	18.25	2.54	3.72	0.01	2.87	2.29	40.2	40.7	14.3	45.5	48.2
	(2.12)	(2.58)	5.88	(4.70)	(4.30)	(1.41)	(1.53)	(0.72)	1.83	(1.53)					
Rotational herbicide	11.45	7.33	39.33	33.33	23.00	0.02	3.40	0.92	3.15	1.87	32.8	42.4	4.2	20.0	37.3
	(3.03)	(2.44)	6.17	(5.80)	(4.77)	(0.72)	(1.62)	(1.13)	1.89	(1.49)					
Weed free check	1.53	4.67	24.67	17.33	13.17	0.02	1.17	0.47	2.20	0.96	90.9	68.7	40.2	57.2	64.3
	(1.23)	(2.02)	4.91	(4.20)	(3.68)	(0.72)	(1.13)	(0.96)	1.64	(1.19)					
Weedy check	14.26	9.44	41.33	42.67	35.73	2.82	9.20	0.68	2.93	3.91	-	-	-	-	-
	(3.73)	(3.05)	6.33	(6.56)	(6.00)	(1.29)	(2.49)	(1.02)	1.85	(1.89)					
LSD (p=0.05)	(NS)	(NS)	(NS)	(0.72)	(1.05)	(NS)	(NS)	(NS)	(NS)	(NS)					

Figures in parentheses indicate square root transformations $\sqrt{x+0.5}$; NS: Non-significant, Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations; PE: pre-emergence

free check (two hand weeding) (49.82% and 64.35% at 30 and 50 DAT respectively) followed by application of pretilachlor-S.

Grain and straw yields

Green manuring significantly influenced the grain and straw yields of rice and produced significantly higher grain and straw yields (3.86 grain and 3.87 straw t/ha) as compared to without green manuring (**Table 5**). This was due to effective suppression of weeds, restricting the nutrient drain by weeds and nutrient addition due to incorporation of green manuring. Apart from better weed control, mineralization of nutrients from incorporated green manuring might have resulted in higher grain yield (Matiwade and Sheelavantar 1994, Nalini *et al*. 2008).

Weed control measures significantly influence the grain yield of rice (**Table 5**). Weed free check (two hand weeding) produced significantly the highest grain yield (3.92 t/ha pooled) of rice over use of fixed application of pretilachlor-S (3.54 t/ha pooled) and rotational herbicides (pyrazosulfuron 0.030 kg/ha at 8-10 DAT, I year)**,** fenoxaprop -p-ethyl 0.056 kg/ha at 25-30 DAT, II year**,** oxadiargyl 0.100 kg/ha at 0-5 DAT, III year, (3.44 t/ha pooled), while it was at par with application of pretilachlor-S and rotational herbicides during 2011 and 2012 with rotational herbicide. Various weed control measures did not influence significantly the straw yield of rice. Use of pretilachlor-S recorded only 8.41% reduction in grain yield compared to weed free check, (two hand weeding) followed rotational use of herbicide (pyrazosulfuron 0.030 kg/ha at 8-10 DAT, I year),

Table 5. Effects of green manuring and weed control measures on yield of rice

Treatment	Grain (t/ha)					Straw (t/ha)					Weed index (%)				
	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled
Green manuring															
Green manuring	3.77	4.87	3.07	3.13	3.86	3.83	4.89	3.62	3.74	3.87	-	-	-	-	
Without green manuring	2.44	3.65	2.97	3.00	3.17	2.10	3.77	3.04	3.60	2.98	-	-	-	-	
LSD (p=0.05)	0.48	0.57	(NS)	(NS)	0.21	0.24	0.67	(NS)	(NS)	0.43	-	-	-	-	
Weed control measure															
Fixed herbicide – pretilachlor-S (PE)	3.43	4.33	3.18	3.14	3.54	3.32	4.46	3.36	3.61	3.50	3.57	4.56	0.46	14.77	6.38
Rotational herbicide	3.15	4.18	2.89	2.87	3.44	2.78	4.17	3.33	3.39	3.42	15.29	9.34	5.33	20.96	8.78
Weed free check	3.65	4.61	3.20	3.49	3.92	3.35	4.60	3.37	4.43	3.60	-	-	-	-	
Weedy check	2.19	4.03	2.82	2.27	3.16	2.41	4.09	3.27	2.83	3.18	34.29	11.83	7.31	35.61	15.69
LSD (p=0.05)	0.64	0.37	(NS)	0.18	0.30	0.45	(NS)	(NS)	0.22	(NS)	-	-	-	-	

NS: Non-significant, Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations; PE: pre-emergence fenoxaprop -p-ethyl 0.056 kg/ha at 25-30 DAT, II year, oxadiargyl 0.100 kg/ha at 0-5 DAT, III year, (pooled of three years 12.39%). Similar findings were also reported by Teja *et al.* (2016).

From four years study, it was concluded that incorporation of green manure reduced the weed growth and application of fixed herbicide pretilachlor-S reduced the weed growth and increased the yield of rice under Konkan region of Maharashtra, India.

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Interaction of different conservational practices and weed management on soil biological properties in rice-wheat system

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ABSTRACT

Intensive tillage in the rice-wheat system affects soil microbial health by use of agrochemicals, particularly herbicides for control of weeds. Tillage and crop rotation also affects microbial immobilization of soil nutrients. Tillage and agrochemical load directly or indirectly affect the performance of different soil microbial health and its functions which supports the soil health, plant growth and ultimately crop performance. Thus, learning about the interaction of different conservational practices and weed management in terms of soil biological properties is extremely necessary. Hence, the present study was conducted at N.E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture & Technology, Pantnagar (Uttarakhand) during 2015-16 to 2016-17 with 5 establishments methods of rice and 3 weed management practices under strip plot design with three replications. Conventional Agricultural practices with weed management practices had a significant impact on soil biological properties *i.e.* dehydrogenase activity, acid, and alkaline phosphatase activity, during both the years. The value of dehydrogenase, acid, and alkaline phosphatase activity was higher in zero till rice and wheat with retention of residues followed by *Sesbania* brown manuring in summers (ZTR+R-ZTW+R-ZTS) with a weedy check, during both the years of study.

INTRODUCTION

Soil biological properties involve soil micro-organisms and soil enzymes that play a major role in soil health in particular immobilization of soil nutrients required for the plant growth and development. They reflect the minute change in the soil environment and thus, considered as sensitive biological indicators of soil quality evaluation. Soil enzymes catalyze various reactions for biological assessment of soil processes like dehydrogenase, phosphatase, and urease. The dehydrogenase activity is an indicator of biological activity in soils (Burns 1978). Phosphatase catalyzes hydrolytic break down of phosphomonoesters, which is correlated between the amount of soil phosphorus and fertility. Urease enzyme catalyzes the hydrolysis of urea to CO_2 and NH_4^+ ions. It is important as it mediates the conversion of organic nitrogen to inorganic nitrogen and has been widely used to evaluate the changes in soil fertility (Nazreen *et al.* 2012). However, adoption of continuous intensive tillage in the rice-wheat system has affected the soil microbial health by use of agrochemicals, particularly herbicides for control of weeds. Conventional tillage leads to the impairment of soil microbiological activity and enzyme activities (Acosta-Martinez *et al.* 2003). Herbicide usage has increased by the time of green revolution which also resulted in leaching of herbicides and accumulating in the top 0 to 15 cm soil depth causing huge damage to the life processes of the micro-organism, which ultimately affects the soil health (Latha and Gopal 2010). Thus, a study was conducted with an objective to find out the interaction effect of different conservational practices and weed management on soil biological properties, *viz.* dehydrogenase, phosphatase and urease activity in the soil.

MATERIALS AND METHODS

A field experiment was conducted in 2015-16 to 2016-17 at N.E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture & Technology, Pantnagar (Uttarakhand). The site is situated at 29°N latitude and 79.32°E longitude having an altitude of 243.8 m above the mean sea level. The experiment, comprising 5 establishment methods of rice in vertical strip, *viz.* conventional transplanted rice (TPR-CT), TPR-CT followed by *Sesbania* as green manure, direct seeded rice (DSR) fb *Sesbania* incorporation, zero-till direct seeded rice (ZT-DSR) fb *Sesbania* as brown manure and ZT-DSR with retention of residues of previous wheat crop along with *Sesbania* as brown manure and 3 weed control measures in horizontal strip, *viz.* unweeded control, recommended herbicide *i.e.* bispyribac-sodium 20 g/ha as post-emergence and integrated weed management *i.e.* herbicide application *fb* 1 hand weeding at 45 DAS/DAT, was laid out in strip plot design with a total of 15 treatments replicated thrice in clay loam soil. Under ZT condition, the *Sesbania* was knocked down by 2,4-D application at 30 days after sowing and used as brown manure. After sowing of the crop, residue of the previous crop (wheat residue in rice and vice versa) was applied manually in the plots according to the treatments. Bispyribac-sodium 20 g/ha was applied after 25 days of sowing by using 500 litre volume of water/ha with knap sack sprayer fitted with flat fan boom nozzle Paliwal *et al.* (2017).

The soil sample collected was divided into 2 parts. One partwas stored at 4°C for enzymatic studies while the other part was shade dried, processed and analyzed to determine the fertility status of the soil. Soil dehydrogenase, phosphatase and urease activity was determined by Casida *et al.* (1964), Tabatabai and Bremner (1969) and Bremmer and Douglas (1971), respectively. The data was statistically analyzed adopting statistical package CPCS-1, designed and developed by Punjab Agricultural University, Ludhiana (Cheema and Singh 1991).

RESULTS AND DISCUSSION

Soil dehydrogenase activity (µg TPF/hr/g soil)

A significant interaction of establishment methods of rice and weed management practices on dehydrogenase activity was obtained during 2015 after the harvest of rice, while it was non-significant during 2016. However, after both the years of wheat harvest (2015-16 and 2016-17), a significant interaction was recorded.

Zero-till rice and wheat with retention of residues followed by *Sesbania* brown manuring (ZTR+R-ZTW+R-ZTS) under weedy check recorded highest soil dehydrogenase activity, after harvest of the crop, which was at par with application of bispyribac-Na 20 g/ha post-emergence (PoE) after harvest of rice during 2015, while was significantly superior over ready mix application of clodinafop + Metsulfuron-methyl (MSM) 64 g/ha and integrated approaches of weed management (IWM) practice after harvest of wheat, during both the years (**Table 1 and 2**). Zero till under weedy situation reported 61 and 65.2% higher activity of dehydrogenase after harvest of rice and wheat, respectively.

Soil acid phosphatase activity (µg p-nitrophenol released/hr/g soil)

Establishment methods of rice and wheat with weed management practices showed significant interaction on soil acid phosphatase activity during both the years, after the crop harvest.

Table 1. Interaction of establishment methods and weed management on soil dehydrogenase activity after rice harvest (*Kharif* 2015)

Treatment	TPR-CTW	TPR-ZTW-ZTS	DSR- CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS
Bispyribac-Na 20 g/ha PoE	15.8	18.8	19.3	29.2	37.0
IWM (bispyribac-Na 20 g/ha PoE *fb* 1 HW at 45 DAS/DAT)	14.8	16.7	18.1	27.9	33.7
Weedy check	16.9	29.2	24.8	34.5	38.0
LSD (p=0.05)			1.3		

Table 2. Interaction effect of establishment methods and weed management on soil dehydrogenase activity after wheat harvest (*Rabi* 2015-16 and 2016-17)

Treatment	2015-16					2016-17				
	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS
Ready mix clodinafop + MSM 64 g/ha PoE	14.3	18.1	17.5	25.7	34.4	14.1	16.7	18.0	25.5	34.4
IWM (clodinafop + MSM 64 g/ha PoE *fb*1 HW at 45 DAS)	12.6	16.8	16.4	24.6	31.2	12.6	16.4	16.4	24.6	31.2
Weedy check	16.5	21.3	26.5	33.6	36.2	16.4	26.5	21.3	33.2	36.2
LSD (p=0.05)			1.3					1.2		

TPR= Transplanted rice, DSR=Direct seeded Rice, ZTR=Zero tillage rice, CTW=conventionally tilled wheat, ZTW=Zero tilled wheat, ZTS=Zero tilled *Sesbania*, R=Residue retention

Integration of zero till rice and wheat with retention of residues and *Sesbania* brown manuring under weedy check recorded significantly highest acid phosphatase activity of the soil which was significantly superior to the sole herbicidal application and IWM practice, during both the years of study (**Table 3 and 4**). However, after harvest of rice, similar results were observed during 2016, which was found at par with of zero till rice and wheat with *Sesbania* brown manure (ZTR-ZTW-ZTS) **(Table 3)**. Zero till under weedy situation reported 62.2 and 56.4% higher activity of acid phosphatase after harvest of rice, during 2015 and 2016, respectively. However, there was increment of 62.9 and 62.6% after wheat harvest, during respective years of 2015-16 and 2016-17.

Soil alkaline phosphatase activity (µg p-nitrophenol released/hr/g soil)

Establishment methods of rice and wheat with weed management practices showed significant interaction on soil acid phosphatase activity during both the years, after the crop harvest.

Integration of zero till rice and wheat with as well as without residue retention followed by *Sesbania* brown manure (ZTR-ZTW-ZTS and ZTR+R-ZTW+R-ZTS) under weedy check recorded at par alkaline phosphatase activity of the soil, after the harvest of crops, which was significantly superior to either herbicide applied alone as PoE or herbicide integrated with manual operation post-emergence herbicidal application and IWM practices both during the years (**Table 5 and 6**).

There was 48.2 and 41.7% increase in activity of alkaline phosphatase after harvest of rice, during 2015 and 2016, respectively under zero till weedy condition. While, slight increase of 44.8 and 44.7% was observed after wheat harvest also, during respective years of 2015-16 and 2016-17.

Soil urease activity (mg urea/hr/g soil)

No significant interaction was found with different establishment methods of rice and wheat and weed management practices on urease activity of soil after the harvest of crops, during both the years.

Tillage or crop rotation affects microbial immobilization of soil nutrients. Thus, study revealed that enzyme activity was higher in zero till rice and wheat with retention of residues followed by *Sesbania* brown manuring (ZTR+R-ZTW+R-ZTS) with a weedy check, during both the years of study. This was in close conformity with Celik *et al.* (2011). This indicates that puddling and flooding conditions had detrimental effects on soil microbes and reduce their activities (Unger *et al.* 2009). Zero tillage with 20% residue retention was found to be suitable for soil health and achieving optimum yield (Alam *et al.* 2014). Maximum soil respiration and enzyme activities (acid, alkaline phosphatase and dehydrogenase) were recorded in zero tillage due to improvement in physicochemical and biological properties of soil (Kumar *et al.* 2016). On the other hand, more weeds resulted in high under-ground biomass, which acts as a carbon source for the growth and activity of micro-organisms (Sebiomo *et al.* 2011). The results are in close agreement with the findings of Rao *et al.* (2012).

Table 3. Interaction of establishment methods and weed management on soil acid phosphatase activity after rice harvest (*Kharif* 2015 and 2016)

Treatment	2015					2016				
	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS
Bispyribac-Na 20 g/ha PoE	52.8	88.5	56.1	80.3	109.5	48.2	87.6	48.8	75.3	98.6
IWM (bispyribac-Na 20 g/ha PoE *fb*1 HW at 45 DAS/DAT)	48.7	58.5	47.1	60.4	94.4	48.3	51.3	42.2	56.9	88.5
Weedy check	61.4	104.4	110.8	112.0	128.8	61.3	99.2	103.6	106.3	110.6
LSD (p=0.05)	6.8					5.4				

Table 4. Interaction effect of establishment methods and weed management on soil acid phosphatase activity after wheat harvest (*Rabi* 2015-16 and 2016-17)

Treatment	2015-16					2016-17				
	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS
Ready mix clodinafop + MSM 64 g/ha PoE	50.5	81.7	51.5	75.4	103.2	50.3	80.9	50.3	75.2	99.9
IWM (clodinafop + MSM 64 g/ha PoE*fb*1 HW at 45 DAS)	44.8	51.8	42.2	57.9	91.2	44.7	51.2	41.8	57.3	91.0
Weedy check	59.2	100.2	105.4	107.5	120.7	58.9	100.0	103.2	107.1	119.4
LSD (p=0.05)	4.0					4.1				

TPR= Transplanted rice, DSR= Direct-seeded Rice, ZTR= Zero tillage rice, CTW= Conventionally tilled wheat, ZTW= Zero tilled wheat, ZTS= Zero tilled *Sesbania*, R= Residue retention

Table 5. Interaction of establishment methods and weed management on soil alkaline phosphatase activity after rice harvest (*Kharif* 2015 and 2016)

Treatment	2015					2016				
	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS
Bispyribac-Na 20 g/ha PoE	136.1	137.9	127.6	144.1	153.2	136.7	146.3	132.0	146.5	159.6
IWM (bispyribac-Na 20 g/ha PoE *fb*1 HW at 45 DAS/DAT)	99.2	133.2	43.0	140.5	150.5	112.9	138.3	89.6	143.3	153.6
Weedy check	149.5	179.5	176.6	186.6	191.5	153.2	181.1	176.6	189.3	193.5
LSD (p=0.05)	6.8					8.1				

Table 6. Interaction effect of establishment methods and weed management on soil alkaline phosphatase activity after wheat harvest (*Rabi* 2015-16 and 2016-17)

Treatment	2015-16					2016-17				
	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS	TPR-CTW	TPR-ZTW-ZTS	DSR-CTW-ZTS	ZTR-ZTW-ZTS	ZTR+R-ZTW+R-ZTS
Ready mix clodinafop + MSM 64 g/ha PoE	128.5	129.2	113.5	133.4	139.5	127.8	129.0	113.5	133.1	139.0
IWM (clodinafop + MSM 64 g/ha PoE*fb*1 HW at 45 DAS)	95.4	124.6	42.9	132.8	138.6	95.3	124.5	42.5	132.0	137.9
Weedy check	137.2	153.6	152.1	160.5	172.9	136.9	153.0	151.6	160.1	172.4
LSD (p=0.05)	5.1					5.1				

TPR= Transplanted rice, DSR= Direct-seeded Rice, ZTR= Zero tillage rice, CTW= Conventionally tilled wheat, ZTW= Zero tilled wheat, ZTS= Zero tilled *Sesbania*, R= Residue retention

The lower dehydrogenase activity observed in bispyribac sodium applied alone due to less substrate availability (Raj *et al.* 2015).

It was concluded that conventional agriculture practices with weed management practices had a significant impact on soil biological properties *i.e.* dehydrogenase, acid and alkaline phosphatase activity, during both the years. Thus, the present investigation resulted in that zero-till practice under weedy situation considerably improved the soil health. As IWM and herbicidal application, practices have lowered substrate availability for the microbes and thus the biological activity of soil microbes got declined.

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Penoxsulam + cyhalofop-butyl (premix) evaluation for control of complex weed flora in transplanted rice and its residual effects in rice-wheat cropping system

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ABSTRACT

Field experiments were conducted to evaluate the efficacy of penoxsulam 1.02% w/w (1.0% w/v) + cyhalofop-butyl 5.1% w/w (5.0% w/v) as post-emergence (PoE) in transplanted rice at CCS Haryana Agricultural University, Regional Research Station, Karnal during *kharif* 2010 to 2011, along with its phyto-toxicity on rice crop (*Kharif* 2010 to 2012), residual phyto-toxicity on wheat crop (*Rabi* 2010-11 to 2012-13), its residual studies in soil, straw and rice grains in lab (2017) and also multi-locational adaptive trials on rice during *Kharif* 2017. Penoxsulam + cyhalofop 135 g/ha reduced the density and dry weight of *Echinochloa crusgalli* and other aerobic grassy weeds (0.0- 3.3/m^2 and 0.0-26.3 g/m^2) and broad-leaf weeds (30.7-36.7/m^2 and 0.0-4.7 g/m^2) over its lower doses (105 and 120 g/ha) and was at par with its higher dose (150 g/ha), and it provided almost complete control of sedges during both the years. There was no significant effect of herbicidal treatments on the plant height and panicle length of the crop during both the years. Penoxsulam + cyhalofop 135 g/ha resulted in significantly higher number of effective tillers/ mrl (49.0 in 2010 and 53.3 in 2011) than cyhalofop 80 g/ha (33.8.0 in 2010 and 49.8 in 2011) and weedy check (27.0 in 2010 and 32.5 in 2011), and penoxsulam + cyhalofop 105 g/ha during 2011 (46.5 in 2010 and 51.5 in 2011). The grain yield in plots treated with penoxsulam + cyhalofop 135 g/ha (5.46 t/ha in 2010 and 5.53 t/ha in 2011) was higher than its lower doses (105 and 120 g/ha) and at par with higher dose (150 g/ha) during both the years. Penoxsulam + cyhalofop 135 g/ha provided grain yields similar to penoxsulam 22.5 g/ha, pretilachlor 750 g/ha, butachlor 1500 g/ha and weed free check; and higher than cyhalofop 80 g/ha, bispyribac-sodium 20 g/ha and weedy check during both the years. Weeds growing throughout the crop season caused 68.8% and 45.8% reduction in the grain yield during 2010 and 2011, respectively. Penoxsulam + cyhalofop 135 g/ha provided net returns (` 24945-29325/ha) and B-C ratio (1.80-1.91) almost similar/ higher to recommended PoE application of penoxsulam 22.5 g/ha (` 23756-29368/ha; 1.79-1.95). There was no phyto-toxicity of penoxsulam + cyhalofop even up to 600 g/ha on transplanted rice as well as succeeding wheat crop. Residues of penoxsulam + cyhalofop applied at 135 and 270 g/ha were below detectable level in soil, straw and grains of rice at harvest during 2010-11 to 2012-13. Penoxsulam + cyhalofop 135 g/ha applied at 15-20 DAT in rice (scented as well as coarse rice varieties) at 12 locations provided 92-97% control of weeds and average grain yield of 4.13 t/ha as compared to 3.83 t/ha in check herbicide bispyribac-sodium 25 g/ha. Penoxsulam + cyhalofop 135 g/ha resulted in average total monetary gain of ` 9665/ha and a net returns of ` 8465/ha.

INTRODUCTION

Rice is the staple food of more than 60% of the world population and there is urgent need to increase productivity and production to meet the food demands of the consistently growing population (Fageria 2007). It is grown in India over an area of 44 m ha with total production of 105 m tones, amounting to 40% of the total food grain (Economic Survey 2015-16). Productivity of rice is low in the country and among different constraints, weeds pose a major threat. Weed infestation in transplanted rice in India has been reported to cause yield reductions of 27-68% (Yadav *et al.* 2009, Manhas *et al.* 2012, Duary *et al.* 2015, Hossain and Malik 2017). Most of currently recommended herbicides (butaclor, pretilachlor, anilofos and oxadiargyl) for transplanted rice are applied as pre-emergence (PE). Which many a time do not perform well particularly when crop is subjected to water scarce conditions immediately after transplanting. Hence, there is need for post-emergence herbicides for control of complex weed flora in transplanted rice. Penoxsulam has been reported very effective in controlling of complex weed flora in transplanted rice (Mishra *et al.* 2007, Yadav *et al.* 2008) but its recommended application window of 8-12 days after transplanting (DAT) as spray in puddle transplanted rice fields is a practical limitation. Bispyribac-sodium is most commonly being used herbicide for post-emergence (PoE) control of weeds in transplanted rice (Yadav *et al.* 2009). However, some of grassy, few broad-leaf weeds and sedges are not controlled effectively by alone application of these herbicides and farmers often use 2,4-D, premix of chlorimuron + metsulfuron, ethoxysulfuron or pyrazosulfuron as sequential post-emergence herbicides or tank mixture for control of diverse weed flora. Generally, single application of premix or tank-mix combination of herbicides either pre-emergence or PoE would be more economically option for effective management of weeds. Spray of PoE combination is generally preferred over PE as it offers opportunity to choose the suitable herbicides according to weed flora infesting the crop. Moreover, combination of herbicides could be better option to control broad spectrum of weeds, save time and reduce cost of cultivation.

Penoxsulam 1.02% w/w (1.0% w/v) + cyhalofop-butyl 5.1% w/w (5.0% w/v) is a new ready-mix PoE herbicide for broad spectrum weed control in transplanted rice (Kailkhura *et al.* 2015, Singh *et al.* 2016, Hossain and Malik 2017). Although recommended herbicides penoxsulam and bispyribac-sodium provide effective control of *Echinochloa* along with few broad-leaf weeds and sedges, but increasing infestation of other aerobic grassy weeds such as *Leptochloa chinensis*, *Eragrostis* sp.) in rice fields particularly in situations of water scarcity calls for better weed management strategy. Hence, a read-mix combination of penoxsulam + cyhalofop was evaluated for control of broad spectrum of weeds in transplanted rice, along with its evaluation at farmers' fields, and residual carry over in soil, rice straw and grains.

MATERIALS AND METHODS

On-station experiment

Bio-efficacy studies: A field experiment was conducted to evaluate the efficacy of penoxsulam 1.02% w/w (1.0%w/v) + cyhalofop-butyl 5.1% w/w (5.0% w/v) for weed control during *Kharif* 2010 and *Kharif* 2011, and its phyto-toxicity on rice crop *Kharif* 2010 to 2012 as well as residual phyto-toxicity on wheat crop during *Rabi* 2010-11 to 2012-13, residue analysis in *Kharif* 2017 at CCS HAU Regional Research Station, Karnal and multi-location adaptive trials at farmers' fields in *Kharif* 2017. The soil of the experimental field was clay loam in texture, low in available nitrogen, medium in P_2O_5 and high in available K_2O with slightly alkaline reaction (pH 8.2). The treatments included penoxsulam + cyhalofop 105, 120, 135, 150 g/ha at 15-20 DAT, penoxsulam 22.5 g/ha at 8-12 DAT, cyhalofop-butyl 80 g/ha at 18-20 DAT, bispyribac-sodium 20 g/ha at 10-14 DAT, pretilachlor 750 g/ha at 0-3 DAT (pre-emergence as sand mixed broadcast), butachlor 1500 g/ha at 0-3 DAT along with weed free and weedy checks. The experiment was laid out in randomized block design with three replications. Rice cultivar HKR 47 was transplanted (35 days old seedlings) done on 5 July, 2010 and 20 July 2011, at a spacing of 20 x 15 cm in a plot size of 6.1 x 2.4 m. The post-emergence (PoE) herbicides were applied as spray using knap-sack sprayer fitted with flat fan nozzle in a spray volume of 300 litre/ha, and the pre-emergence (PE) herbicides as sand mix broadcast using 150 kg sand/ha. Soil in the field was kept under saturated condition during spray application and re-irrigated after 24 hours of spray. Crop was raised as per the recommendations of the CCS HAU and harvested on 19 October, 2010 and 30 October, 2011. Density and dry weight of weeds were recorded at 60 days after transplanting (DAT), and yield attributes and yield at were recorded maturity. Crop injury in respect of phyto-toxicity symptoms (yellowing, chlorosis, stunting or scorching) under different treatments was also recorded by visual rating (0-100%) at 15, 30 and 45 days after herbicide application (DAA). Since there was no crop injury on rice crop, data pertaining to this observation are not presented herein.

Phyto-toxicity studies: A field experiment was conducted to study the phyto-toxicity of penoxsulam + cyhalofop-butyl on transplanted rice at CCS HAU Regional Research Station, Karnal during *Kharif* 2010 to 2012. The treatments included penoxsulam + cyhalofop 150, 300 and 600 g/ha at 15-20 DAT along with untreated check with three replications. During *Kharif* 2010, 35 days old nursery of rice cv. '*HKR-47*' was transplanted on 5 July. During 2011, 42 days old nursery of rice cv. '*HKR 47*' was transplanted on 20 July. During 2012, 36 days old nursery of rice cv. '*HKR 47*' was transplanted on 12 July. The transplanting was done at a spacing of 20 x 15 cm in a plot size of 6.1 x 2.4 m. Herbicides spray and other agronomic practices were the same as mentioned in previous section. The crop harvested on 19 October, 2010, 30 October, 2011 and 23 October 2012. Observations (from 10 plants/plot) on crop phyto-toxicity in terms of vein clearing, epinasty, hyponasty, wilting and injury to leaf tips and leaf surface were recorded at 1, 3, 5, 7, 10, 15 and 30 days after herbicide application, on 0-10 scale with 0= no phyto-toxicty and 10= compete mortality.

Maintaining the same plots, sowing of wheat crop was done at row spacing of 20 cm on 19 November 2010 (*DBW 17*), 25 November 2011 (*DPW 621-50*) and 20 November 2012 (*DPW 621-50*), using seed rate of 100-112.5 kg/ha. Crop was raised as per package of practices of the CCS HAU. Observations (from 10 plants/ plot) on crop phyto-toxicity for rice were recorded at 15 and 30 DAS.

Residue studies: Residual studies in soil, straw and grains of rice were conducted during 2017 when technical grade herbicide with testing protocol was made available by the manufacturing company. For residual studies, a field experiment was laid out at CCS HAU Regional Research Station, Karnal during *Kharif* 2017. The treatments included penoxsulam + cyhalofop-butyl at 135 (X), 270 g/ha (2X) and untreated check. One month old seedlings of rice cultivar '*HKR-47*' were transplanted on 13 July at a spacing of 20 x 15 cm in a plot size of 16 x 6 m. Crop was raised as per the recommendations of the CCS HAU and harvested on 20 October. Samples of grain, straw and soil were collected at harvest for residue estimation. After validation of analytical method, the sample of soil, straw and grains of rice after harvest were analysed for residues of penoxsulam and cyhalofop on HPLC and of cyhalofop-butyl on GC-MS/MS. The limits of detection of herbicides and the MRL standards are given below.

MRL standards are given below.	
Limit of detection (LOD):	0.005 ug/g (for penoxsulam on HPLC) 0.001 ug/g (for cyhalofop on GC-MS/MS)
Limit of quantification (LOQ):	0.01 ug/g (for penoxsulam on HPLC) 0.005 ug/g (for cyhalofop on GC-MS/MS)
MRL in rice grain:	0.02 ug/g (US Environment Protection Agency, 2004) 0.02 ug/g (European Food Safety Authority, 2013)
MRL in rice straw:	0.5 ug/g (US Environment Protection Agency, 2004) 0.02 ug/g (European Food Safety Authority, 2013)

On-farm adaptive trials

To assess the performance of the herbicide on large scale in real field situations, adaptive trials at farmers' fields were conducted during *Kharif* 2017 with commercial formulation of penoxsulam+ cyhalofop-butyl made available by the company. Adaptive trials were conducted at 12 locations at farmers' fields in Karnal, Kurukshetra and Panipat districts during *Kharif* 2017. The fields were infested with complex weed flora. Penoxsulam + cyhalofop 135 g/ha at 15-20 DAT was evaluated in comparison to the check herbicide bispyribac-sodium 25 g/ha at 15-25 DAT. Herbicides were applied as spray in 300 litre water/ ha. The area under each treatment was 0.2 ha at each site.

Statistical analysis

Before statistical analysis, the data on density of weeds was subjected to square root ($\sqrt{x+1}$) transformation to improve the homogeneity of the variance. The data were subjected to the analysis of variance (ANOVA) separately for each year. The significant treatment effect was judged with the help of 'F' test at the 5% level of significance. The 'OPSTAT' software of CCS Haryana Agricultural University, Hisar, India was used for statistical analysis (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

On-station experiments

Effect on weeds: During 2010, penoxsulam + cyhalofop 135 g/ha resulted in significantly lower density of grassy weeds (0.0- 3.3/m^2) than its lower doses (105 and 120 g/ha) and further reduction in density of grassy weeds with its higher dose (150 g/ ha) was not significant over 135 g /ha (**Table 1**). It resulted in density of grassy weeds lower than penoxsulam 22.5 g/ha, cyhalofop 80 g/ha, pretilachlor 750 g/ha, bispyribac-sodium 20 g/ha, but was at par with butachlor 1500 g/ha. However, this dose (135 g/ha) was inferior to weed free check in respect of density of grassy weeds.

During 2011, density of *Echinochloa* under penoxsulam + cyhalofop 135 g/ha was lower than its lower doses and at par with its higher dose (**Table 1**). Penoxsulam + cyhalofop 135 g/ha resulted in density of *Echinochloa* at par with penoxsulam 22.5 g/ha, butachlor 1500 g/ha and weed free check, and lower than other treatments. Density of other grassy weeds (*Leptochloa chinenesis* and *Eragrostis* sp.) under penoxsulam + cyhalofop 135 g/ha was lower than penoxsulam + cyhalofop 105 g/ha but at par with its other doses. Penoxsulam + cyhalofop 135 g/ha resulted in density of aerobic grassy weeds at par with cyhalofop 80 g/ha, pretilachlor 750 g/ha and butachlor 1500 g/ha and weed free check, and lower than all other treatments.

During 2010, penoxsulam + cyhalofop 135 g/ha resulted in density of broadleaf weeds (BLW) (36.7/m^2) at par with all its other doses; penoxsulam 22.5 g/ha, bispyribac-sodium 20 g/ha, pretilachlor 750 g/ha and butachlor 1500 g/ha (**Table 1**). Penoxsulam + cyhalofop 135 g/ha was superior to cyhalofop 80 g/ha and weedy check, but was inferior to weed free conditions in respect of density of BLW. During 2011, penoxsulam + cyhalofop 135 g/ha resulted in density of BLW (30.7/m^2) lower than its lower doses (105 and 120 g/ha); and at par with its higher dose as well as with penoxsulam 22.5 g/ha and butachlor 1500 g/ha (**Table 1**). Penoxsulam + cyhalofop 135 g/ha was superior to cyhalofop 80 g/ha, bispyribac-sodium, pretilachlor and weedy check in respect of density of BLW. However, it was inferior to weed free check in controlling the weeds.

The data of sedge were recorded in 2011 (**Table 1**). Penoxsulam + cyhalofop 135 g/ha provided almost complete control of sedges and registered superiority over cyhalofop 80 g/ha and weedy check and was at par with all other treatments in respect of density of sedges.

Dry weight of weeds: During 2010, application of penoxsulam + cyhalofop 135 g/ha resulted in significantly lower dry weight of grassy weeds (26.3 g/m^2) than its lower doses (105 and 120 g/ha) and at par with its higher dose of 150 g/ha (**Table 2**). It also resulted in significantly lower dry weight of grassy weeds than cyhalofop 80 g/ha and weedy check.

During 2011, dry weight of *Echinochloa* under penoxsulam + cyhalofop 135 g/ha was lower than its lower doses (105 and 120 g/ha) (**Table 2**). However, penoxsulam + cyhalofop 6% OD 135 g/ha was at par with its higher dose (150 g/ha) and with penoxsulam 22.5 g/ha, butachlor 1500 g/ha and weed free check in reducing dry weight of *Echinochloa*. Dry weight of aerobic grassy weeds under penoxsulam + cyhalofop 135 g/ha was also lower than penoxsulam + cyhalofop 105 g/ha but at par with its other doses as well as with cyhalofop 80 g/ha, pretilachlor 750 g/ha and butachlor 1500 g/ha and weed free check, but lower than bispyribac-sodium 20 g/ha and weedy check.

During 2010, penoxsulam + cyhalofop 135 g/ha caused significant reduction in dry weight of broadleaf weeds (4.7 g/m^2) over than its lower doses but was at par with its higher dose. During 2011, penoxsulam + cyhalofop 135 g/ha was superior to its dose of 105 g/ha but at par with other doses. Penoxsulam + cyhalofop 135 g/ha was also superior to cyhalofop 80 g/ha and weedy check in respect of dry weight of BLW, in both years. Penoxsulam + cyhalofop 135 g/ha provided almost complete control of sedges, was markedly superior to cyhalofop 80 g/ha and weedy check in respect of dry weight of sedges during 2011 (**Table 2**).

Penoxsulam (Yadav *et al.* 2008) and bispyribac-sodium (Yadav *et al.* 2009) applied as PoE have already been reported very effective against *E.*

Table 1. Effect of penoxsulam + cyhalofop on density of weeds (no./m^2) in transplanted rice during *Kharif* 2010 and 2011

Treatment	2010		2011					
	Echino-chloa spp.	BLW	*Echino-chloa* spp.	Other grassy weeds	BLW	*Cyperus difformis*	*Fimbristylis miliaceae*	Total sedges
Penoxsulam + cyhalofop (105 g/ha) 15-20 DAT	4.99(24.0)	7.11(50.7)	2.92(8.0)	1.8(2.7)	8.0(64.0)	1.0(0)	1.4(1.3)	1.4(1.3)
Penoxsulam + cyhalofop (120 g/ha) 5-20 DAT	4.18(16.7)	6.44(42.0)	2.49(5.3)	1.2(0.7)	7.4(54.0)	1.0(0)	1.0(0.0)	1.0(0)
Penoxsulam + cyhalofop (135 g/ha) 5-20 DAT	2.04(3.3)	6.07(36.7)	1.00 (0)	1.0(0)	5.6(30.7)	1.0(0)	1.0(0.0)	1.0(0)
Penoxsulam + cyhalofop (150 g/ha) 5-20 DAT	1.66(2.0)	6.00(35.3)	1.00(0)	1.0(0)	5.6(30.0)	1.0(0)	1.0(0.0)	1.0(0)
Penoxsulam (22.5 g/ha) 8-12 DAT	3.19(9.3)	6.28(38.7)	1.41(1.3)	2.3(4.7)	6.1(36.0)	1.0(0)	1.0(0.0)	1.0(0)
Cyhalofop (80 g/ha) 18-20 DAT	6.68(44.7)	10.1(103.3)	3.57(12.7)	1.0(0)	8.9(78.7)	4.2(17.3)	2.5(6.7)	5.0(24.0)
Bispyribac-sodium (20 g/ha) 10-14 DAT	4.68(21.3)	6.98(48.0)	2.32(5.3)	1.8(2.7)	7.5(56.0)	1.4(1.3)	1.0(0.0)	1.4(1.3)
Bispyribac-sodium (25 g/ha) 15-25 DAT	2.75(6.7)	6.43(41.3)	1.00(0)	1.8(2.7)	6.6(42.7)	1.0(0)	1.2(0.7)	1.2(0.7)
Pretilachlor (750 g/ha) 0-3 DAT	3.29(10.0)	6.36(40.0)	2.33(5.3)	1.0(0)	7.4(54.0)	1.0(0)	1.0(0.0)	1.0(0)
Butachlor (1500 g/ha) 0-3 DAT	1.66(2.0)	5.60(30.7)	1.66(2.0)	1.0(0)	5.7(32.0)	1.0(0)	1.0(0.0)	1.0(0)
Weed free	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.0(0)	1.0(0)	1.0(0)	1.0(0.0)	1.0(0)
Weedy check	7.37(54.0)	9.67(92.7)	4.72(21.3)	2.4(5.3)	10.1(102.0)	4.6(20.7)	2.8(8.7)	5.5(29.3)
LSD (p=0.05)	1.03	1.67	1.25	0.62	1.44	0.59	1.03	0.75

Original figures given in parenthesis were subjected to square root transformation ($\sqrt{x+1}$); Efore statistical analysis; DAT - Days after transplanting; BLW - broad-leaf weeds *crusgalli* and *E. colona,* few broad-leaf weeds and sedges, but not against other grasses such as *Leptochloa, Eragrostis, Dactyloctenium etc*. Application of cyhalofop 80 g/ha alone proved less effective in reducing density and dry weight of complex weed flora, than combined application of penoxsulam + cyhalofop 135 g/ha in transplanted rice (Singh *et al*. 2016). Kailkhura *et al*. (2015) and Hossain and Malik (2017) also found effective control of complex weed flora in transplanted rice with premix application of penoxsulam + cyhalofop 135 g/ha. However, Menon *et al*. (2016) reported poor efficacy of this herbicide combination against *Ludwigia parviflora*.

Effect on crop: There was no significant effect of herbicide treatments on the plant height and panicle length of the crop during both the years (**Table 3**). Penoxsulam + cyhalofop 135 g/ha resulted in similar number of effective tillers/ mrl (49.0 in 2010 and 53.3 in 2011) to be at par with all other treatments except being higher than penoxsulam + cyhalofop 105 g/ha (51.5 in 2011), cyhalofop 80 g/ha (33.8.0 in 2010 and 49.8 in 2011) and weedy check (27.0 in 2010 and 32.5 in 2011). The grain yield under penoxsulam + cyhalofop 135 g/ha (5.46 t/ha in 2010 and 5.53 t/ha in 2011) was significantly higher than its lower doses (105 and 120 g/ha) and at par with higher dose (150 g/ha) during both the years, indicating it to be the optimum dose. Penoxsulam + cyhalofop 135 g/ha also resulted in grain yields similar to penoxsulam 22.5 g/ha, pretilachlor 750 g/ha, butachlor 1500 g/ha and weed free check; but higher than cyhalofop 80 g/ha, bispyribac-sodium 20 g/ha and weedy check during both the years. These results are in agreement with earlier findings from different locations (Kailkhura *et al*. 2015, Singh *et al*. 2016, Hossain and Malik 2017). Weeds growing throughout the crop season reduced the grain yield to the extent of 68.8% and 45.8% during 2010 and 2011, respectively.

Table 2. Effect of penoxsulam + cyhalofop on dry-weight of weeds (g/m^2) in transplanted rice during *Kharif* 2010 and 2011

Treatment	Dose (g/ha)	Time (DAT)	2010		2011			
			Grassy weeds	BLW*	*Echinochloa* spp	Other grasses	BLW	Sedges
Penoxsulam + cyhalofop	105	15-20	140.0	9.5	59.8	2.5	3.1	0.7
Penoxsulam + cyhalofop	120	15-20	72.6	7.3	39.4	0.7	2.5	0.0
Penoxsulam + cyhalofop	135	15-20	26.3	4.7	0.0	0.0	1.1	0.0
Penoxsulam + cyhalofop	150	15-20	28.6	4.2	0.0	0.0	1.4	0.0
Penoxsulam	22.5	8-12	35.5	4.1	16.5	6.0	1.5	0.0
Cyhalofop	80	18-20	316.3	10.1	162.1	0.0	7.0	11.3
Bispyribac-sodium	20	10-14	46.6	7.7	35.9	2.8	3.9	0.5
Bispyribac-sodium	25	15-25	29.9	5.9	0.0	2.7	2.3	0.3
Pretilachlor	750	0-3	51.1	7.1	37.3	0.0	0.9	0.0
Butachlor	1500	0-3	17.3	3.9	14.8	0.0	0.4	0.0
Weed free			0.0	0.0	0.0	0.0	0.0	0.0
Weedy check			433.5	10.3	311.0	6.1	7.5	13.9
LSD (p=0.05)			35.8	3.0	35.0	1.9	1.6	2.9

*BLW, broad-leaf weeds

Table 3. Effect of penoxsulam + cyhalofop on plant height, yield attributes and grain yield of transplanted rice during *Kharif* 2010 and 2011

Treatment	Dose (g/ha)	Time (DAT)	Plant height (cm)		Effective tillers/ mrl		Panicle length (cm)		Grain yield (t/ha)	
			2010	2011	2010	2011	2010	2011	2010	2011
Penoxsulam + cyhalofop	105	15-20	114.9	95.8	46.5	51.5	22.1	20.2	4.63	4.89
Penoxsulam + cyhalofop	120	15-20	114.8	95.7	49.0	53.3	22.4	20.0	4.86	5.15
Penoxsulam + cyhalofop	135	15-20	115.5	93.8	53.3	58.0	22.3	20.5	5.46	5.53
Penoxsulam + cyhalofop	150	15-20	115.5	95.5	52.7	57.3	22.5	20.5	5.44	5.58
Penoxsulam	22.5	8-12	115.4	94.3	52.0	57.2	22.3	20.3	5.22	5.42
Cyhalofop	80	18-20	114.5	94.1	33.8	49.8	21.7	19.9	3.44	5.07
Bispyribac-sodium	20	10-14	115.9	94.9	50.3	53.7	21.9	20.1	5.14	5.23
Bispyribac-sodium	25	15-25	115.4	95.3	53.0	56.5	22.1	20.3	5.32	5.41
Pretilachlor	750	0-3	114.7	96.1	50.7	54.0	22.0	20.0	5.19	5.27
Butachlor	1500	0-3	115.7	94.5	54.5	58.2	22.6	20.2	5.53	5.46
Weed free			119.9	94.3	56.8	60.0	22.2	20.1	5.77	5.60
Weedy check			113.4	94.0	27.0	32.5	21.5	19.7	1.80	3.03
LSD (p=0.05)			NS	NS	6.9	6.1	NS	NS	0.32	0.32

The grain yield and yield attributing characters were lower during 2010 as compared to 2011 owing to high infestation of weeds during 2010.

Economics: Penoxsulam + cyhalofop 135 g/ha provided net returns of ` 24945-29325/ha, which was almost similar/ higher than recommended post-em herbicide penoxsulam 22.5 g/ha (` 23756-29368/ha). Penoxsulam + cyhalofop 135 g/ha offered B-C ratio of 1.80-1.91, which was also almost similar to penoxsulam (**Table 4**). Singh *et al.* (2016) also reported improvement in grain yield, net returns and B-C ratio with this combination in transplanted rice.

Phyto-toxicity studies: There was no phyto-toxicity of penoxsulam + cyhalofop even up to 600 g/ha on transplanted rice at 1, 3, 5, 7, 10, 15 and 30 days after application (DAA) of the herbicide during *Kharif* 2010 to 2012 or on the succeeding wheat crop during *Rabi* seasons of 2010-11 to 2012-13

Residue studies: Residues of penoxsulam+ cyhalofop applied at 135 and 270 g/ha were below detectable level in soil, straw and grains of rice at harvest during 2017 which indicated its safety to the human/animal health and the environment.

On- farm adaptive trials: Penoxsulam + cyhalofop 135 g/ha provided 92-97% control of weeds and resulted in average grain yield of 4.13 t/ha as compared to 85-92% weed control and grain yield of 3.83 t/ha in check herbicide bispyribac-sodium 25 g/ha (**Table 5**). Penoxsulam + cyhalofop 6%OD 135 g/ha increased the gross monetary returns by ` 9665/ha with additional cost of ` 1200/ha, thus giving a net gain of ` 8465/ha due to increase in productivity (**Table 6**).

Table 4. Effect of penoxsulam + cyhalofop on economics of transplanted rice during *Kharif* 2010 and 2011

Treatment	Dose (g/ha)	Time (DAT)	Variable cost (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C ratio	
			2010	2011	2010	2011	2010	2011	2010	2011
Penoxsulam + cyhalofop	105	15-20	30.65	31.45	47.71	54.33	17.06	22.89	1.56	1.73
Penoxsulam + cyhalofop	120	15-20	30.96	31.76	50.04	57.22	19.07	25.46	1.62	1.80
Penoxsulam + cyhalofop	135	15-20	31.27	32.07	56.22	61.39	24.94	29.32	1.80	1.91
Penoxsulam + cyhalofop	150	15-20	31.58	32.38	56.07	61.90	24.49	29.52	1.78	1.91
Penoxsulam	22.5	8-12	30.03	30.83	53.79	60.19	23.76	29.37	1.79	1.95
Cyhalofop	80	18-20	29.72	30.52	35.41	56.29	5.69	25.77	1.19	1.84
Bispyribac-sodium	20	10-14	29.72	30.52	52.92	58.01	23.20	27.49	1.78	1.90
Bispyribac-sodium	25	15-25	30.03	30.83	54.75	60.09	24.72	29.27	1.82	1.95
Pretilachlor	750	0-3	29.07	29.84	53.45	58.54	24.38	28.70	1.84	1.96
Butachlor	1500	0-3	29.02	29.79	56.99	60.62	27.97	30.82	1.96	2.03
Weed free			34.85	37.44	59.45	62.22	24.60	24.77	1.71	1.66
Weedy check			28.13	28.85	18.53	33.69	-9.60	4.84	0.66	1.17

Table 5. Performance of penxsulam + cyhalofop-butyl against weeds in transplanted rice in adaptive trials conducted at farmers' fields in *Kharif* 2017

District	Location	Variety	Weed control (%)		Grain yield (t/ha)	
			Penxsulam + cyhalofop 135 g/ha	Bispyribac-sodium 25 g/ha	Penxsulam + cyhalofop 135 g/ha	Bispyribac-sodium 25 g/ha
Karnal	Uchana-1	CSR-30	95	90	3.52	3.25
Karnal	Uchana-2	CSR-30	96	91	3.46	3.24
Karnal	Tikri	HKR 47	97	90	6.81	6.43
Karnal	Shindarpur	PB 1121	94	92	4.02	3.86
Karnal	Uchani-1	PB 1121	95	90	4.15	3.82
Karnal	Uchani-2	CSR -30	95	90	2.95	2.86
Karnal	Popra	PB 1121	94	86	3.82	3.42
Karnal	Kunjpura	PB 1121	93	85	3.64	3.35
Karnal	Panhari	HKR 47	95	90	6.72	6.34
Kuruksetra	Darala	CSR-30	94	89	2.92	2.73
Panipat	Ishrana	PB 1121	95	88	3.82	3.45
Panipat	Dhurana	PB 1121	92	85	3.75	3.22
Average			94.6	88.8	4.13	3.83

Table 6. Net gains from use of penoxsulam + cyhalofop in adaptive trials conducted at farmers' fields in *Kharif* 2017

Variety	No. of locations	Average grain yield (t/ha)		Increase in grain yield over check herbicide (t/ha)	Total monetary gain over check herbicide (`/ha)	Additional cost of test herbicide over check (`/ha)	Net monetary gain (`/ha)
		Penxsulam + cyhalofop (135 g/ha)	Check herbicide (bispyribac-sodium 25 g/ha)				
Basmati rice (*CSR-30*)	4	3.21	3.02	0.19	7600	1200	6400
Basmati rice (*Pusa basmati 1121*)	6	3.87	3.52	0.35	12250	1200	11050
Coarse grain rice (*HKR 47*)	2	6.77	6.39	0.38	6042	1200	4842
Average		4.13	3.83	0.30	9665	1200	8465

The present investigation suggests that penoxsulam + cyhalofop (ready-mix) 135 g/ha applied at 15-20 DAT in a spray volume of 300 litre water/ha could be alternative option for effective and economic control of complex weed flora and attain significant improvement in grain yield of transplanted rice.

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Weed management and rapeseed mustard productivity in conservation agriculture based rice - yellow mustard - greengram cropping system in lateritic belt of West Bengal

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ABSTRACT

A field experiment was conducted during 2015-16 and 2016-17 at Agriculture Farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal to study the effect of tillage and weed management practices on weed growth and productivity of yellow mustard in direct-seeded rice - yellow mustard - greengram cropping system. The experiment was laid out in a strip plot design with four horizontal tillage strips and three vertical weed management strips replicated thrice. Results revealed that conservational tillage (zero tillage + residue) along with recommended herbicide (RH) (pendimethalin at 0.75 kg/ha) + one hand weeding (HW) recorded the lower values of total weed density (6.20 and 6.43 no/m^2) and dry weight (1.22 and 1.42 g/m^2) and higher values of seed yield (1.20 and 1.46 t/ha) in first and second year, respectively. In second year, conservational tillage even with RH alone registered at par values of total weed density and dry weight with conventional tillage + RH + 1 HW and it also recorded 10.2% higher seed yield than conventional tillage + RH + 1 HW. Thus, conservation tillage along with recommended herbicide alone in yellow mustard appeared to be a promising technique with respect to weed suppression and productivity of yellow mustard in conservation agriculture based rice-mustard sarson-greengram cropping system.

INTRODUCTION

Rice - yellow mustard (yellow sarson) - greengram is one of the predominant cropping systems in eastern India providing food, vegetable oil and protein. The productivity of yellow mustard in rice-yellow mustard system is far below than its potential yield due to many constraints. The major contributory causes are delayed sowing due to late harvesting of preceding long duration rice varieties and soil wetness and moisture stress at critical stage of the crop growth resulting in reduced yield (Duary *et al.* 2016a). *Rabi* season in eastern India is characterized with short and mild winter. Proper utilization of short and mild winter is one of the major challenges for the cultivation of *Rabi* crops. Time of sowing is an important non monetary input for obtaining higher yield in rapeseed-mustard. In the lateritic belt of West Bengal, the optimum time of sowing of the crop is last week of October to the second fortnight of November (Duary *et al.* 2016b). Late transplanting and delayed harvesting of rice usually result in late sowing of succeeding rapeseed-mustard when raised under conventional method of sowing which in turn reduces the yield significantly. However, this yield reduction can be minimized through manipulation of tillage operations enabling early sowing of rapeseed-mustard by adopting reduced tillage systems. Zero tillage (ZT) can advance the sowing time through a single tractor operation using a specially designed seed-cum-fertilizer drill. However, ZT practices are more advantageous when crop residues are retained on the soil surface, which serves as physical barrier towards emergence of weeds, moderate soil temperature, conserve soil moisture add organic matter and solve the problem of air pollution arising due to large-scale burning of straw residues (Sharma *et al.* 2012). Thus conservation agriculture (CA) is a viable alternative which is suitable for today's limited natural resources and changing climate (Nichols *et al.* 2015).

Conservation agriculture systems, comprising no or minimum mechanical soil disturbance, organic mulch soil cover and crop diversification, in conjunction with other good practices of crop and production management are now practiced globally on about 157 Mha (Kassam *et al.* 2015). In India, over the past few years, the adoption of ZT and CA has expanded to cover about 1.5 million hectares (Jat *et al.* 2014). Heavy weed infestation in initial years is the major hindrance in wide-scale adoption of conservation agriculture technologies. However, it has been experienced that weed problems gradually decrease after a few years of true conservation agriculture (Sharma and Singh 2014). Weed management has been recognized as an essential component of CA and, thus, requires special attention. In CA, weed can be controlled manually or by using herbicides. However, labour is becoming expensive and is rarely available at the critical time of weeding. Herbicides are being extensively used in CA, but there is no single herbicide which can be applied for a wide spectrum of weeds. Hence, integrated weed management is highly desirable to enhance the sustainability of CA. Keeping this in view, a field experiment was carried out to study the effect of tillage and weed management practices on weed growth and productivity of yellow mustard in a conservation agriculture based rice-yellow mustard – greengram cropping system.

MATERIALS AND METHODS

A field experiment was conducted during 2015-16 and 2016-17 at Agriculture Farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal. The soil of the experimental field was sandy loam in texture with acidic reaction (5.72) and low in available nitrogen (158.3 kg/ha), P_2O_5 (38.75 kg/ha), K_2O (102.5 kg/ha) and organic carbon (0.39%).

The experiment was laid out in a strip plot design with three replications. Four tillage practices comprising of conventional tillage (CT) (direct-seeded rice) — CT (yellow mustard) — CT (greengram), CT (direct-seeded rice) — zero tillage (ZT) (yellow mustard) — ZT (greengram), ZT (direct-seeded rice) — ZT (yellow mustard) — ZT (greengram), ZT + residue (R) (direct-seeded rice) — ZT + R (yellow mustard) — ZT + R (greengram) were allocated to the horizontal strip and three weed management practices, *viz.* recommended herbicides (RH) (pendimethalin at 1.0 kg/ha followed by bispyribac-sodium at 25 g/ha in direct-seeded rice, pendimethalin at 0.75 kg/ha each in yellow mustard and greengram), Recommended herbicides + hand weeding (HW) at 35 days after sowing (DAS), Unweeded control were assigned to the vertical strip. Pre-sowing (12 days before sowing) application of glyphosate was done at 1.0 kg/ha on the established weeds in zero and conservation tillage plots. Full amount of crop residue (100%) of direct seeded rice, yellow mustard and greengram from respective treatments of conservation tillage were retained in the plot itself. Crop varieties *'MTU-1010'*, *'B-9'* and *'Samrat'* were used for rice, yellow sarson, and greengram, respectively. Direct-seeded rice, yellow mustard and greengram were mechanically sown with zero till ferti-seed drill machine (National Zero Till Ferti-Seed drill, Ludhiana). The line to line spacing of zero-till drill was adjusted at 20 cm for direct-seeded rice and 30 cm each for yellow mustard and greengram. Seed rate was fixed by adjusting the lever at 60 kg/ha for direct seeded rice, 5 kg/ha for yellow mustard and 25 kg/ha for greengram. Recommended N, P_2O_5 and K_2O at 80:40:40 kg/ha in rice, 80:40:40 kg/ha in yellow mustard and 20:40:40 kg/ha in greengram were applied as per recommended practice. In yellow mustard full amount of phosphorus and potash and half of the nitrogen was applied as basal at the time of sowing. The remaining dose of nitrogen was top dressed at the pre-flowering stage (at first irrigation). A basal dose of nutrients were drilled through 10-26-26 and urea. Hand operated knapsack sprayer fitted with a flat fan type nozzle was used for spraying the herbicides with a spray volume of 500 litres/ha. All other recommended agronomic practices were followed and plant protection measures were adopted as per need. The density of monocot and dicot weeds was recorded at 45 DAS by placing a quadrat of 50 × 50 cm from the marked sampling area of 1.0 m^2 in each plot. For recording their biomass, weed samples were sun-dried and later oven dried at 70^o C until constant weight was attained. The data were subjected to a square root transformation to normalize their distribution. Yield attributes and seed yield of yellow mustard was recorded at harvest and statistically analyzed at a 5% level of significance.

RESULTS AND DISCUSSION

The total number of weed species was 16 out of which *Echinochloa colona, Digitaria sanguinalis, Cynodon dactylon* and *Cyanotis axillaris* among monocots and *Ageratum conyzoides, Spilanthes paniculata, Polygonum plebeium, Gnapahalium purpureum, Chenopodium album, Physalis minima, Eclipta alba, Oldenlandia corymbosa, Cleome viscosa, Ludwigia parviflora, Solanum nigrum* and *Indigofera hirsuta* among dicots made the composition of weed flora in yellow mustard field. Duary *et al.* (2015) also reported similar weed flora in yellow mustard.

Tillage and weed management practices exerted significant influence on density and dry weight of monocot, dicot and total weeds at 45 DAS in both the years. Among different tillage practices conventional tillage (CT-CT-CT) recorded significantly the lowest density of monocot weeds at 45 DAS in the first year but in the second year it was the lowest under conventional *fb* zero tillage (CT-ZT-ZT) having no significant difference with conservation tillage (ZT+R- ZT+R- ZT+R) (**Table 1**). All tillage practices except zero tillage (ZT-ZT-ZT) recorded at par values of dry weight of monocot weeds in the first year while in the second year it was significantly the lowest under conservation tillage (ZT+R- ZT+R- ZT+R). Conservation tillage (ZT+R- ZT+R- ZT+R) recorded the lowest density and dry weight of dicot weeds at 45 DAS and was statistically at par with zero tillage (ZT-ZT-ZT) during both years of study. Although conservation tillage (ZT+R- ZT+R- ZT+R) registered at par values of total weed density with conventional tillage (CT-CT-CT) in the first year but in the second year the lowest density of total weeds was noticed under conservation tillage (ZT+R- ZT+R- ZT+R). Conservation tillage (ZT+R- ZT+R- ZT+R) maintained significant superiority over other tillage practices in registering the lowest total weed dry weight at 45 DAS in both the years accounting 8.3 and 67.5% lower than conventional tillage (CT-CT-CT) in the first and second year, respectively (**Table 1**).

Under conservation tillage (ZT+R- ZT+R- ZT+R) the minimum disturbance of soil might have contributed to the unfavourable conditions for germination at the surface which prevented the emergence of weeds (Sharma and Singh 2014). The retention of previous crops residues under conservation tillage might have suppressed the weed growth by influencing light transmittance, soil temperature, soil moisture and enhancing weed seed predation (Nichols *et al.* 2015). Among weed management practices pre-emergence application of pendimethalin at 0.75 kg/ha + one HW at 35 DAS recorded significantly the lowest density and dry weight of monocot, dicot and total weeds at 45 DAS in both the years (**Table 1**). Mitra (2011) and Patel *et al.* (2013) also reported similar efficacy of pendimethalin followed by one HW in reducing the density and dry weight of total weeds. Interaction effect on density and dry weight of monocot, dicot and total weeds at 45 DAS in both the years (**Figure 1-4**) expressed that conventional tillage (CT-CT-CT) along with RH + 1 HW registered the lowest density of monocot and total weeds at 45 DAS in both the years and remained at par with CT-ZT-ZT + RH+1 HW in the first year and all other tillage practices + RH + 1 HW in the second year. Similarly, the dry weight of monocot and total weeds was the lowest under CT-CT-CT + RH + 1 HW in the first year but under conservation tillage + RH+1 HW in the second year. Even conservation tillage in unweeded plots also registered at par values of dry weight of monocot and total weeds with conventional tillage + RH in the second year. All tillage practices with RH + 1 HW registered zero density and dry weight of dicot weeds at 45 DAS in both the years excepting conventional tillage + RH + 1 HW in the second year (**Figure 2 and 4**).

Effect on crop

The highest number of siliquae/plant, seeds/siliqua and test weight was registered under conservation tillage (ZT+R- ZT+R- ZT+R) in both the years and was statistically at par with CT-CT-CT in the first year and with ZT-ZT-ZT in the second year. Although conservation tillage (ZT+R- ZT+R- ZT+R) registered at par values of seed yield with conventional tillage (CT-CT-CT) in the first year but in the second year it registered 35.4, 24.5 and 19.3% higher seed yield than CT-CT-CT, CT-ZT-ZT, and

Table 1. Density and dry weight of weeds in yellow mustard under different tillage and weed management practices at 45 DAS

Treatment	Weed density (no./m^2)						Weed dry weight (g/m^2)					
	Monocot		Dicot		Total		Monocot		Dicot		Total	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Tillage practice												
T_1- CT(DSR) – CT(YS) – CT(G)	11.7	23.6	2.97(8.3)	3.72(13.4)	23.27	39.82	2.56(6.04)	21.05	2.07(3.8)	2.39(5.2)	3.17(9.5)	27.52
T_2- CT(DSR) – ZT(YS) – ZT(G)	15.3	16.7	3.40(11.0)	2.19(4.3)	30.78	22.45	2.46(5.54)	9.21	2.65(6.5)	1.80(2.7)	3.50(11.8)	13.13
T_3- ZT(DSR) – ZT(YS) – ZT(YS)	22.6	21.9	3.03(8.7)	1.78(2.7)	34.83	25.43	2.72(6.89)	9.93	2.46(5.5)	1.48(1.7)	3.59(12.4)	12.25
T_4- ZT(DSR)+R – ZT(YS) + R – ZT(G)+R	20.1	18.8	2.17(4.2)	1.70(2.4)	25.94	21.85	2.57(6.11)	7.03	1.80(2.7)	1.44(1.6)	3.04(8.7)	8.94
LSD (p=0.05)	0.92	2.3	0.17	0.12	2.02	2.13	0.12	2.03	0.13	0.14	0.09	1.80
Weed management practice												
W_1- Recommended herbicide(RH)	14.4	14.6	2.94(8.1)	2.48(5.7)	22.94	21.35	2.38(5.15)	6.36	2.19(4.3)	1.68(2.3)	3.16(9.5)	9.01
W_2- RH + one hand weeding	3.9	6.2	0.71(0)	0.89(0.3)	3.90	6.56	1.11(0.74)	2.22	0.71(0)	0.76(0.1)	1.11(0.7)	2.30
W_3- Unweeded control	33.9	40.1	5.03(24.8)	3.67(13.0)	59.27	54.26	4.24(17.5)	26.84	3.8(14.2)	2.90(7.9)	5.70(31.9)	35.07
LSD (p=0.05)	1.50	0.98	0.26	0.19	3.44	1.63	0.17	1.51	0.24	0.14	0.19	1.43

Figures in parentheses are the original values. The data was transformed to SQRT ($\sqrt{x + 0.5}$) before analysis
CT-Conventional tillage, ZT-Zero tillage, R-Residue, DSR-Direct seeded rice, YS-Yellow mustard

Table 2. Yield attributes and seed yield of yellow mustard as influenced by tillage and weed management practices

Treatment	No. of siliquae/ plant		Seeds/ siliqua		1000 seed Weight (g)		Seed yield (t/ha)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015 -16	2016-17
Tillage practice								
CT (DSR) – CT (YS) – CT (G)	86	73	19	19	2.50	2.43	1.11	0.87
CT (DSR) – ZT (YS) – ZT (G)	82	80	20	20	2.37	2.51	0.99	0.95
ZT (DSR) – ZT (YS) – ZT (G)	75	83	20	21	2.31	2.58	0.95	0.99
ZT (DSR) + R – ZT (YS) + R – ZT (G)+R	87	90	20	21	2.56	2.77	1.07	1.18
LSD (p=0.05)	7.16	7.22	1.44	0.86	0.14	0.14	0.09	0.07
Weed management practice								
Recommended herbicide	85	84	21	21	2.55	2.66	1.07	1.01
Recommended herbicide+ one hand weeding	97	97	21	22	2.61	2.85	1.21	1.24
Unweeded control	65	64	18	18	2.15	2.21	0.80	0.76
LSD (p=0.05)	5.66	6.69	1.83	0.77	0.13	0.15	0.09	0.07

CT-Conventional tillage, ZT-Zero tillage, R-Residue; DSR-Direct-seeded rice, YS-Yellow mustard, G-Greengram

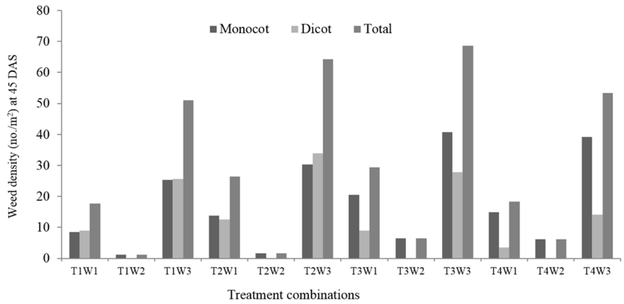

Figure 1. Interaction effect of tillage and weed management practices on density of monocot, dicot and total weeds in yellow mustard at 45 DAS during 2015-16

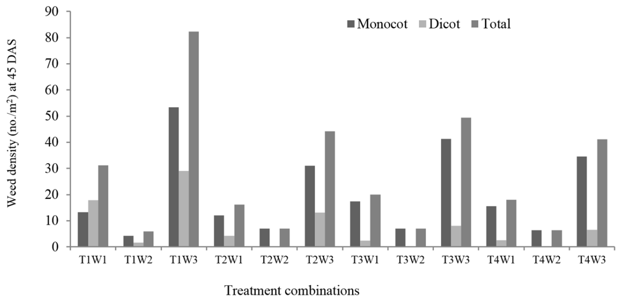

Figure 2. Interaction effect of tillage and weed management practices on density of monocot, dicot and total weeds in yellow mustard at 45 DAS during 2016-17

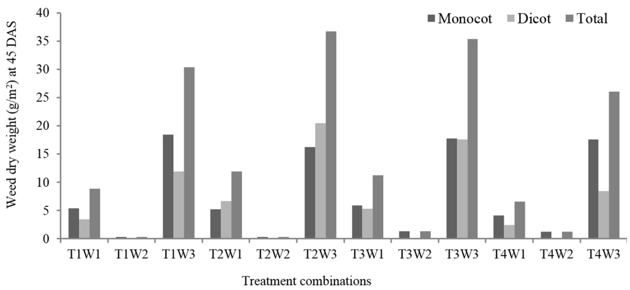

Figure 3. Interaction effect of tillage and weed management practices on dry weight of monocot, dicot and total weeds in yellow mustard at 45 DAS during 2015-16

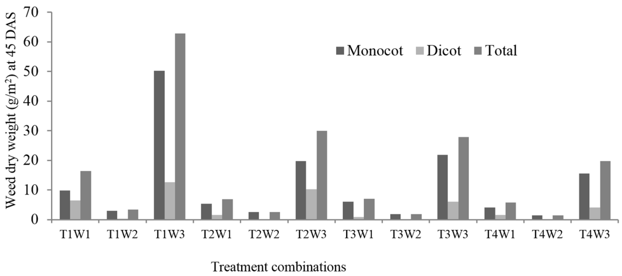

Figure 4. Interaction effect of tillage and weed management practices on dry weight of monocot, dicot and total weeds in yellow mustard at 45 DAS during 2016-17

ZT-ZT-ZT, respectively (**Table 2**). The higher values of yield attributes and seed yield of yellow mustard with conservation tillage was due to favorable influence of zero tillage and cumulative effect of residue retention which helped in greater availability of nutrients that led to increasing in growth and yield attributes and finally the seed yield. Higher yield with residue retention under conservation agriculture was also reported by Das *et al*. (2015) and Nath *et al*. (2015). Significantly the highest values of yield attributes and seed yield were recorded with RH + 1 HW at 35 DAS in both the years (**Table 2**). Significant effect of interaction was observed on number of siliquae/plant, test weight and seed yield of yellow mustard in both the years. Conservation tillage (ZT+R- ZT+R- ZT+R) with RH + 1 HW recorded at par values of siliquae/plant, test weight and seed yield with conventional tillage + RH + 1 HW in first year (**Figure 5**). But in second year, conservation tillage (ZT+R- ZT+R- ZT+R) even with recommended

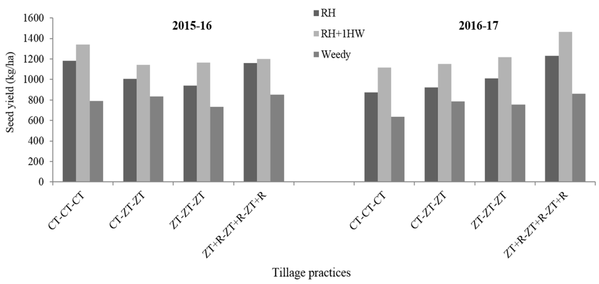

Figure 5. Interaction effect of tillage and weed management practices on seed yield of yellow mustard

herbicide only recorded at par values of siliquae /plant and test weight with conventional tillage + RH + 1 HW. Conservation tillage (ZT+R- ZT+R- ZT+R) with recommended herbicide alone recorded 10.2% higher seed yield than conventional tillage + RH + 1 HW in second year (**Figure 5**).

The results revealed the superiority of conservation tillage (ZT+R-ZT+R-ZT+R) than other tillage practices irrespective of with or without weed management. Residue retention and zero tillage are fundamental principles of conservation tillage, which themselves are the methods of weed control providing weed free environment during critical period of growth stages. The competition between crops and weeds was less from the very early stage of the crop till maturity facilitating higher nutrient and water uptake, accelerated photosynthetic activity, availability of optimum space for better crop growth resulting into higher dry matter accumulation and higher values of growth attributes and partitioning of dry matter towards seed formation (Das *et al.* 2015 and Nath *et al.* 2015).

Thus, after two cycles of CA based rice-yellow mustard-greengram cropping system, conservation tillage with recommended herbicides and one hand weeding in all the crops resulted in effective weed management and higher seed yield of yellow mustard. However, conservation tillage along with recommended herbicide alone in yellow mustard appeared to be a promising technique as it was as good as conventional tillage with integrated use of recommended herbicide and hand weeding with respect to weed suppression and productivity of yellow mustard in conservation agriculture based rice - yellow mustard - greengram cropping system.

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Herbicide mixtures for weed control in dual purpose tall wheat and pendimethalin residue in wheat fodder and soil

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ABSTRACT

Weeds are the biological constraints to increase wheat productivity in Asia. A field experiment was conducted during the *Rabi* seasons of 2015-16 and 2016-17 to evaluate the efficacy of pendimethalin, pinoxaden, metsulfuron, sulfosulfuron, clodinafop under sole, mixture and their sequential application against control of mixed weed flora in dual purpose wheat at area of farm CCS HAU Hisar (Haryana). The season-long growth of weeds reduced wheat yield up to 55.4 and 59.3% during 2015-16 and 2016-17, respectively. Before cutting of wheat for fodder, among herbicidal treatments, pre-emergence (PE) application of pendimethalin 1500 g/ha significantly reduced grassy (*P. minor*) and broad-leaf weeds dry weight at 25 and 55 days after sowing (DAS) during both the years. After cutting, weed dry weight at 85, 115 DAS and at harvest was significantly reduced under sequential application of pendimethalin 1500 g/ha *fb* pinoxaden + metsulfuron (50 + 4) at 2 week after cutting (WAC) at 55 DAS, pendimethalin 1500 g/ha *fb* sulfosulfuron + metsulfuron (30 + 2) at 2 WAC and pendimethalin 1500 g/ha *fb* clodinafop + metsulfuron (60 + 4) at 2 WAC as compared to alone application of post-emergence (PoE). Among herbicidal treatments, significantly higher weed control efficiency, plant height, total tillers, grain yield and B:C ratio was observed under sequential application of herbicides than alone application of herbicides during both the years of study. Wheat fodder could be used safely for livestock as no residue was reported.

INTRODUCTION

Wheat can be grown as a dual purpose crop where it provides both grain and forage from the same patch of land (Shuja *et al.* 2010). The net profit or income of this system should be higher as both livestock and wheat commodities are available for market. Many factors could be responsible for low yield in wheat, but weed infestation is one of the major causes. Wheat (*Triticum aestivum* L.) is infested with complex weed flora. In India the average yield losses in wheat due to weeds vary from 20 to 32% across different wheat growing regions (Chhokar *et al.* 2008). Montazeri *et al.* (2005) reported that chemical method is most commonly used to control weeds in wheat fields. All types of weeds are not controlled by a single herbicide and the continuous use of a single herbicide results in weed shifts and evolution of herbicide resistance. The presence of mixed weed flora warrants integrated use of herbicides. More recently, in wheat crop, herbicide resistance has been reported in *Phalaris minor* against pinoxaden (Kaur *et al.* 2015), in *Rumex dentatus* against metsulfuron-methyl (Chhokar *et al.* 2017) and in *Avena ludoviciana* against clodinafop (Singh 2016). In dual purpose wheat, once the crop is cut for fodder, the competition from the weeds could be more as the crop will require time to regenerate and attain some growth. Under such situation, tank mixtures and sequential application of herbicides may play critical role to have a broad-spectrum weed control in dual purpose crop.

Wheat fodder is fed to livestock, the estimation of herbicide residue in wheat fodder need to be examined. Also the study of herbicide persistence in soil is required, as it may affects the yield of next growing crop on same piece of land. Schleicher *et al.* (1995) reported that pendimethalin persistence in the soil is affected by soil temperature and moisture conditions. Although determining the herbicide residues in the soil and crop produce is a challenging task because of very low concentration of analyte, as low as maximum residue limit (MRL) is imposed by the regulatory agencies. Therefore, the present experiment was designed for weed management to get maximum productivity and profitability of dual purpose wheat.

MATERIALS AND METHODS

Field experiments were conducted at the research farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India during winter season of 2015-16 and 2016-17. The experimental soil was sandy loam with organic carbon (0.35%), pH (7.9), EC (0.25 mmhos/cm) and was low in available nitrogen (132 kg N/ha), medium in available phosphorous (17 kg P/ha) and high in available potassium (370 kg K/ha). The experimental field had been under irrigated cluster bean-wheat cropping system. The weekly weather data (maximum and minimum temperature and rainfall) during the two growing seasons are represented in **Figure 1**. During second year (2016-17) mean weekly temperature was relatively 2-3^{0}C higher than first year at initial 7-8 weeks period of crop growth and had an adverse impact on growth parameters and yield of crop. The wheat crop received 33 mm rain in 2015-16 and 47.2 mm in 2106-17.

Seedbed preparation consisted of pre-sowing irrigation, ploughing with a disc harrow followed by two passes with a field cultivator followed by planking. Wheat '*C306*' was seeded on October 28, 2015 and October 30, 2016 using seed rate of 100 kg/ha, in 22.5 cm spaced rows. The crop was fertilized by using urea as the source of nitrogen at different doses and in different splits as shown in treatments. Phosphorous was applied at 30 kg P_2O_5/ha through single super phosphate as basal dose. Each year, the experiment was conducted in a randomized complete block design with three replications. Seven treatment combinations consisted of five herbicides *viz*. pendimethalin 1500 g/ha PE alone and followed by (*fb*) post-emergence (PoE) application of pinoxaden 50 g/ha + metsulfuron 4 g/ha, sulfosulfuron + metsulfuron (30 + 2) g/ha and clodinafop + metsulfuron (60 + 4) g/ha at 2 week after cutting (WAC), alone application of pinoxaden 50 g/ha + metsulfuron 4 g/ha, sulfosulfuron + metsulfuron (30+2) g/ha and clodinafop + metsulfuron (60 + 4) g/ha at 2 WAC. A weed-free check and a weedy check were also included for comparison with the herbicide treatments. The plot area was 6.5 × 4.5 m. All herbicides were applied using knapsack sprayer fitted with a flat fan nozzle. The crop was supplied with need based post-sowing irrigations when the soil moisture had declined to one-third of field capacity. All management practices other than the weed control treatments were consistent with the recommended package of practices for the CCS HAU, Hisar. In the weed free treatment, weeds were removed by hand weeding throughout the season. Grassy and broad-leaf weed dry weight was assessed taking, all weeds by using a 0.45 m^2 quadrant placed at two representative locations, in each plot at 25, 55, 85, 115 DAS and at harvest were cut and dried in an oven at 70 ^{o}C for 72 h and then weighed. Weed control efficiency (WCE) was calculated in dual purpose wheat by the formula:

$$\text{WCE (\%)} = \frac{\text{Dry matter of weeds in weedy check- dry matter of weeds in treatment}}{\text{Dry matter of weeds in weedy check}} \times 100$$

After 55 days of sowing, dual purpose wheat crop was harvested for fodder at 5 cm stubble height. Plant height was measured from the ground to the tip of the uppermost leaf from five randomly selected plants in each plot at 55, 85, 115 DAS and at harvest. Total number of tillers was counted in one meter row length in each plot at crop harvest. Spike length from five representative spikes from each plot was measured in cm with scale. The crop was manually harvested at maturity and grain yield was recorded after threshing treatment wise. 1000-grains were counted from the grain yield of each plot and their weight was recorded as test weight of respective treatment. Benefit-cost ratio was calculated.

Data were analyzed using software S.P.S.S version 7.5. to evaluate the differences between treatments. Weed biomass data were square root transformed before performing ANOVA because of high variance. However, non-transformed means are presented with mean separation based on transformed values. Where the ANOVA indicated that treatment effects were significant, means were separated at $p<0.05$ and adjusted with Fisher's Protected Least Significant Difference (LSD) test.

Pendimethalin residue in fodder and soil was carried out at Agrochemicals Residues Testing Laboratory, Department of Agronomy, CCS Haryana Agricultural University, Hisar by GC-MS/MS (Agilent 7890A series).

RESULTS AND DISCUSSION

Weed studies

Before cutting, among herbicidal treatments, application of pendimethalin 1500 g/ha PE, pendimethalin 1500 g/ha PE *fb* pinoxaden +

metsulfuron (50 + 4) at 2 WAC (weeks after cutting), pendimethalin 1500 g/ha PE *fb* sulfosulfuron + metsulfuron (30 + 2) at 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60 + 4) at 2 WAC provided significantly reduced grassy weed (*P. minor*) and broad-leaf weed dry weight, which might be due to efficacy of pendimethalin as a PE herbicide in controlling weed flora in field (**Table 1**).

After cutting of dual purpose wheat for fodder, occurrence of new flush of weeds was observed because of application of irrigation and fertilizer in the field just after cutting of crop. In present experiment, sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50+4) at 2 WAC (week after cutting at 55 DAS), pendimethalin 1500 g/ha PE *fb* sulfosulfuron + metsulfuron (30 + 2) 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60+4) at 2 WAC recorded significantly less dry weight of weeds and higher weed control efficiency (WCE).Weeds under alone application of PE pendimethalin 1500 g/ha, PoE pinoxaden + metsulfuron (50 + 4) at 2 WAC, sulfosulfuron + metsulfuron (30 + 2) at 2 WAC, clodinafop + metsulfuron (60 + 4) at 2 WAC did not show-effective mortality as remaining stubble of weeds after cutting were aged and hardy, thus the alone PoE spray *i.e.* 70 DAS (means 2 weeks after cutting) of herbicides mixtures were less effective against those weeds (**Table 1**). The results are in conformity with Das (2008). But sequential application of PE and POE herbicides provided effective control of weeds. Similarly, sequential application of pendimethalin 1.5 kg/ha PE followed by tank mix pinoxaden + metsulfuron 64 g /ha or mesosulfuron + iodosulfuron 14.4 g/ha or sulfosulfuron + metsulfuron (RM) 32 g/ha PoE provided excellent control of *P. minor* as well as broad-leaf weeds in wheat field (Anonymous, 2015-16). Baghestani *et al.* (2008) also reported that tank-mix or pre-mix use of different herbicide chemistries or sequential application of pre- and post-emergence herbicides at different times showed effective weed control. Dry weight of both grassy and broad-leaf was increased under alone application of pendimethalin 1500 g/ha PE due to emergence of new flush of weeds during the crop season.

A negative relationship was observed between weed dry weight and WCE in the linear regression model (**Figure 2**). The regression model explained about 93.3% of the variation in WCE due to weed biomass and showed a good fit between the WCE and the weed biomass.

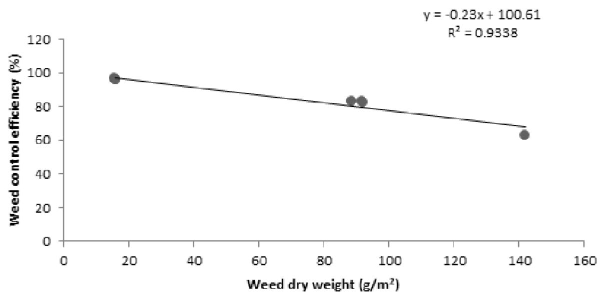


Figure 2. Relationship between weed dry weight and weed control efficiency (WCE). The line represents a linear model fitted to the average data for both the years

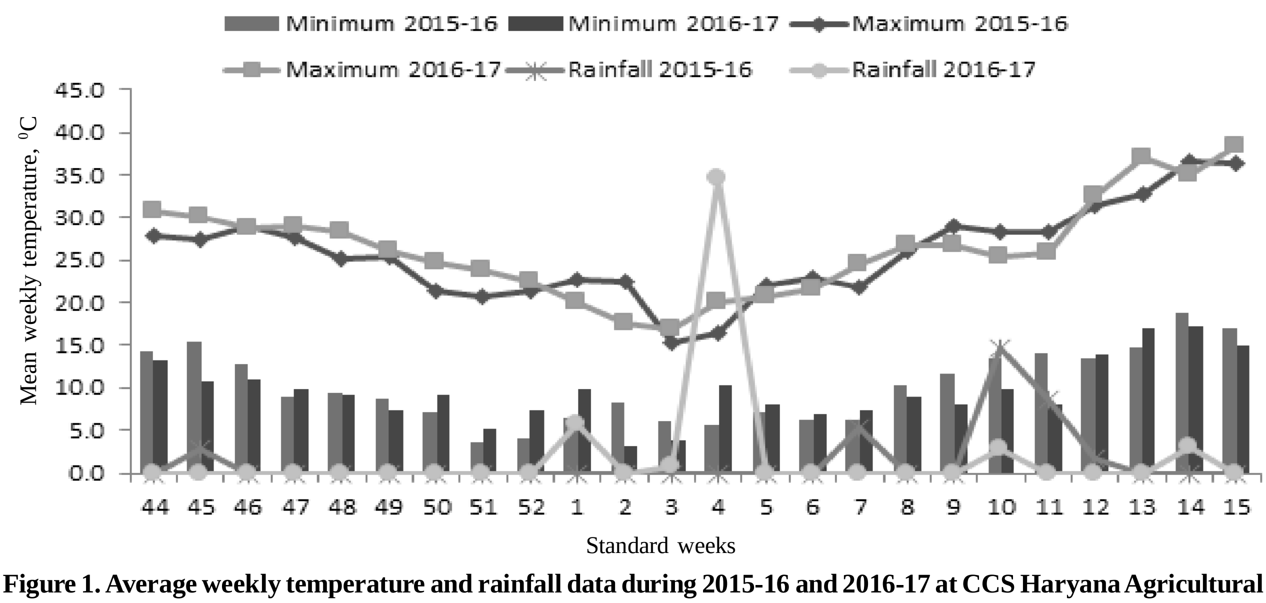
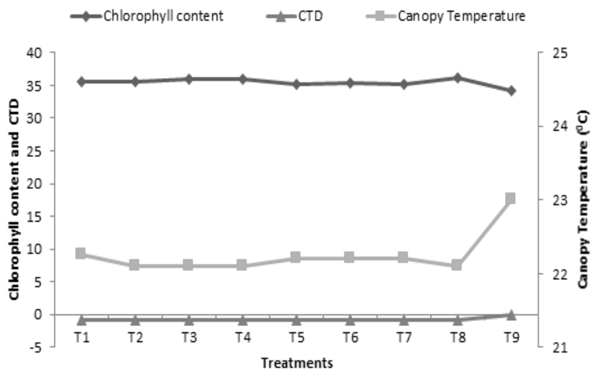


Figure 1. Average weekly temperature and rainfall data during 2015-16 and 2016-17 at CCS Haryana Agricultural University Research Farm, Hisar, India

Crop growth studies and yield

Among different herbicidal treatments, before cutting, significantly more plant height was recorded in all the treatments where pre emergence application of pendimethalin was applied as compared to the alone post-emergence application of herbicides (**Table 2**). After cutting, significantly shorter plants were recorded under alone application of PE pendimethalin 1500 g/ha, PoE pinoxaden + metsulfuron (50 + 4) at 2 WAC, sulfosulfuron + metsulfuron (30 + 2) at 2 WAC and clodinafop + metsulfuron (60 + 4) 2 WAC as compared to sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50 + 4) at 2 WAC, pendimethalin 1500 g/ha PE *fb* sulfosulfuron+ metsulfuron (30 + 2) at 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60 + 4) at 2 WAC at 85 DAS during both the years of study. Chlorophyll content and canopy temperature had not shown any significant difference among different treatments (**Figure 3**).



T1- Pendimethalin 1500 g PE; T2- Pendimethalin 1500 g PE *fb* pinoxadenn + metsulfuron (50 + 4) 2 WAC (weeks after cutting); T3- Pendimethalin 1500 g PE *fb* sulfosulfuron + metsulfuron (30 + 2) 2 WAC; T4- Pendimethalin 1500 g PE *fb* clodinafop + metsulfuron (60 + 4) 2 WAC; T5- Pinoxadenn + metsulfuron (50 + 4) 2 WAC; T6- Sulfosulfuron + metsulfuron (30 + 2) 2 WAC; T7- Clodinafop + metsulfuron (60 + 4) 2 WAC; T8- Weed free; T9- Weedy check

Figure 3. Effect of different herbicides on chlorophyll content (SPAD unit), canopy temperature (°C) and CTD at heading stage of dual purpose wheat

Table 1. Effect of different herbicides on grassy and broad leaf weeds dry weight (pooled data of two years) in dual purpose wheat

Treatment	Dose (g/ha)	Time of application	25 DAS	55 DAS	85 DAS	115 DAS	At harvest
Grassy weed dry weight (g/m^2)							
Pendimethalin	1500	PE	1.3 (0.6)	2.1 (3.4)	2.6 (5.5)	6.3 (37.7)	7.7 (58.4)
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	1.2 (0.5)	2.2 (3.8)	2.3 (4.0)	2.0 (2.9)	2.7 (6.05)
Pendimethalin *fb* sulfosulfuron + metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	1.3 (0.7)	2.2 (3.7)	2.3 (4.3)	2.2 (4.1)	2.8 (6.8)
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE *fb* 2 WAC	1.3 (0.6)	2.3 (3.9)	2.3 (4.4)	2.1 (3.6)	2.8 (7.2)
Pinoxaden + metsulfuron	50 + 4	2 WAC	2.2 (3.5)	5.5 (29.1)	3.5 (11.4)	4.2 (16.4)	5.3 (27.3)
Sulfosulfuron+ metsulfuron	30 + 2	2 WAC	2.2 (3.8)	5.2 (26.0)	3.3 (9.9)	4.2 (16.9)	5.3 (26.4)
Clodinafop + metsulfuron	60 + 4	2 WAC	2.3 (4.2)	5.4 (28.3)	3.5 (10.9)	4.4 (18.5)	5.4 (28.2)
Weed free	-		1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check	-		2.3 (4.25)	5.4 (28.2)	5.8 (32.5)	10.4 (107)	12.6 (157)
LSD (p=0.05)			0.8	1.3	1.5	1.7	1.8
Broad-leaf weed dry weight (g/m^2)							
Pendimethalin	1500	PE	2.0 (2.8)	2.8 (6.9)	3.3 (9.8)	7.7 (58.0)	9.2 (83.8)
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	2.0 (3.0)	2.8 (6.4)	3.5 (10.9)	3.3 (9.8)	3.3 (9.7)
Pendimethalin *fb* sulfosulfuron + metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	1.9 (2.8)	2.5 (5.4)	3.3 (9.7)	2.9 (7.4)	3.2 (9.2)
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE fb 2 WAC	2.2 (2.3)	2.3 (4.3)	3.6 (11.7)	3.1 (8.5)	3.2 (8.8)
Pinoxaden + metsulfuron	50 + 4	2 WAC	3.2 (8.9)	4.6 (19.9)	4.3 (17.6)	6.6 (42.2)	7.9 (62.1)
Sulfosulfuron + metsulfuron	30 + 2	2 WAC	3.0 (7.9)	4.6 (19.5)	4.7 (20.7)	6.5 (41.6)	8.0 (62.5)
Clodinafop + metsulfuron	60 + 4	2 WAC	3.3 (10.1)	4.5 (19.4)	4.5 (19.0)	6.7 (43.1)	8.1 (63.7)
Weed free	-		1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check	-		3.2 (9.2)	5.8 (22.1)	6.7 (44.3)	12.9 (165)	14.5 (210)
LSD (p=0.05)			1.1	1.8	2.5	2.6	2.23

*Original data given in parentheses was subjected to square root transformation

Table 2. Effect of different herbicides on plant height (cm) of dual purpose wheat

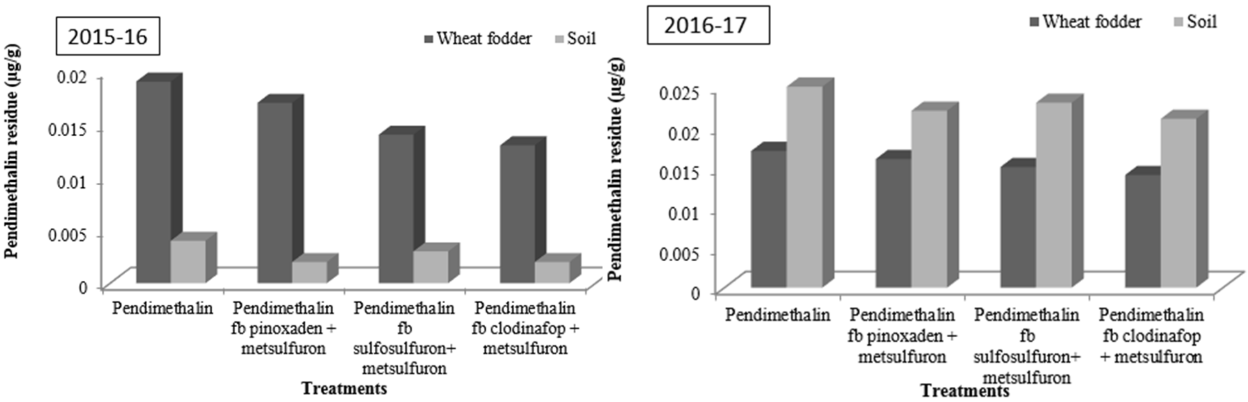
Treatment	Dose (g/ha)	Time of application	Plant height (cm) 2015-16 55 DAS	85 DAS	115 DAS	At harvest	2016-17 55 DAS	85 DAS	115 DAS	At harvest
Pendimethalin	1500	PE	37.2	67.1	98.7	108.9	40.4	71.0	99.7	113.3
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	37.5	71.1	99.9	109.9	40.7	75.4	100.9	114.3
Pendimethalin *fb* sulfosulfuron+ metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	37.3	71.2	100.8	110.9	40.5	75.5	101.8	115.3
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE *fb* 2 WAC	38.3	71.0	100.6	110.7	41.6	75.3	101.6	115.1
Pinoxaden + metsulfuron	50 + 4	2 WAC	35.1	66.8	99.8	109.8	38.1	70.8	100.8	114.2
Sulfosulfuron+ metsulfuron	30 + 2	2 WAC	35.0	66.6	99.6	109.6	38.0	70.7	100.6	113.9
Clodinafop + metsulfuron	60 + 4	2 WAC	34.7	67.0	100.2	110.2	37.7	71.0	101.2	114.6
Weed free	-		39.1	72.9	103.1	113.3	42.4	77.3	104.1	117.8
Weedy check	-		34.5	66.5	97.5	107.3	37.2	70.6	98.5	111.5
LSD (p=0.05)			2.1	1.6	1.8	2.0	2.3	1.7	1.8	2.1

Table 3. Effect of different herbicides on yield attributes and yield of dual purpose wheat

Treatment	Dose (g/ha)	Time of application	Fodder yield (t/ha)	Total tillers (no./m.r.l)	Spike length (cm)	Grain yield (t/ha)	Test weight (g)
2015-16							
Pendimethalin	1500	PE	3.80	83.2	8.4	2.26	42.6
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	3.84	83.1	8.8	2.93	43.2
Pendimethalin *fb* sulfosulfuron+ metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	3.82	84.4	8.8	2.99	43.8
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE *fb* 2 WAC	3.80	83.9	8.7	2.90	43.2
Pinoxaden + metsulfuron	50 + 4	2 WAC	3.70	79.1	8.6	2.60	42.2
Sulfosulfuron+ metsulfuron	30 + 2	2 WAC	3.75	79.3	8.6	2.70	42.7
Clodinafop + metsulfuron	60 + 4	2 WAC	3.72	78.7	8.6	2.64	42.2
Weed free	-		3.84	85.0	8.8	3.09	43.9
Weedy check	-		3.69	75.5	7.9	1.99	40.4
LSD (p=0.05)			NS	2.9	NS	0.19	NS
2016-17							
Pendimethalin	1500	PE	3.62	81.3	8.0	2.01	38.2
Pendimethalin *fb* pinoxaden + metsulfuron	1500 *fb* (50+4)	PE *fb* 2 WAC	3.61	80.9	8.4	2.68	39.4
Pendimethalin *fb* sulfosulfuron+ metsulfuron	1500 *fb* (30+2)	PE *fb* 2 WAC	3.62	81.4	8.5	2.75	39.7
Pendimethalin *fb* clodinafop + metsulfuron	1500 *fb* (60+4)	PE *fb* 2 WAC	3.64	81.1	8.4	2.65	39.3
Pinoxaden + metsulfuron	50 + 4	2 WAC	3.51	77.4	8.3	2.41	38.6
Sulfosulfuron + metsulfuron	30 + 2	2 WAC	3.49	77.3	8.3	2.49	38.8
Clodinafop + metsulfuron	60 + 4	2 WAC	3.51	77.0	8.3	2.40	38.7
Weed free	-		3.62	81.7	8.5	2.79	39.7
Weedy check	-		3.47	73.1	7.8	1.75	37.9
LSD (p=0.05)			NS	2.5	NS	0.14	NS

m.r.l- meter row length

Maximum number of total tillers, higher grain yield and B: C ratio were observed with weed free which were statistically at par with sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50 + 4) at 2 WAC, pendimethalin 1500 g/ha PE *fb* sulfosulfuron+ metsulfuron (30 + 2) at 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60 + 4) after 2 WAC which might be due to the reason that weed control by sequential application of herbicides and their mixture helped in reducing the competition of crop plants with weeds. The results corroborates with the findings of Anonymous, (2015-16). Sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50 + 4) 2 WAC, pendimethalin 1500 g/ha PE *fb* sulfosulfuron+ metsulfuron (30 + 2) 2 WAC and pendimethalin 1500 g/ha PE *fb* clodinafop + metsulfuron (60 + 4) 2 WAC recorded 32.18%, 33.5% and 31.4%, higher grain yield, respectively than weedy check.



Limit of detection (LOD) - 0.001 µg; Limit of quantification (LOQ) - 0.003 µg; Maximum residue limit (MRL) of 0.05 µg/g

Figure 4. Pendimethalin residue (µg/g) in wheat fodder and soil

However, weed control treatments had no significant effect on fodder yield of dual purpose wheat at 55 DAS during both years of experimentation (**Table 3**).

Residue of pendimethalin in wheat fodder and soil

The detected residue of pendimethalin in wheat fodder and soil during both the crop seasons were below the maximum residue limit (MRL) of 0.05 µg/g set by European Food Safety Authority (EFSA) that won't affect the livestock and next succeeding crop (**Figure 4**). During second crop season, slightly high residue of pendimethalin was reported in soil which might be due to less microbial activity because of increase in 2-3^{0}C temperature in initial crop period during second year (**Figure 1**). But, the residue was below the maximum residual limit and succeeding crop won't be affected. This result corroborates with Gasper *et al.* (1994) that cultivation, soil temperature and moisture conditions had affected pendimethalin persistence in soil and it adsorbs rapidly and strongly to soil because of its high potential for hydrogen bonding.

Based on this study, it can be concluded that without any residual effect on fodder sequential application of pendimethalin 1500 g/ha PE *fb* pinoxaden + metsulfuron (50 + 4) g/ha or sulfosulfuron + metsulfuron (30 + 2) g/ha or clodinafop + metsulfuron (60 + 4) g/ha at 2 WAC provided effective management of weeds and higher crop productivity of dual purpose wheat.

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Control of *Phalaris minor* with sequential application of pre- and post-emergence herbicides and herbicide combinations in wheat

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ABSTRACT

The field efficacy of pre- and post-emergence herbicides and rotational use of different group of herbicides were tested against *Phalaris minor* in wheat on farmers' fields during the year 2015-16 and 2016-17. Clodinafop is being used by 64% farmers at Makowal and 44% at village Mallu Nangal from the last five years. None of the farmer was using pre-emergence herbicide. The higher herbicide dose (76% at site I and 80% at site II) coupled with hallow cone nozzle and less quantity of water (200-225 l/ha) resulted in poor control of *P.minor*. At site I, continuous use of clodinafop resulted in poor weed control efficiency (58.7%) with lower grain yield (4.46 t/ha). Sequential application of pre-emergence herbicide pendimethalin followed by post-emergence application of clodinafop provided effective control of *P.minor* (WCE 76.8%) and significantly higher yield (5.1 t/ha) over the existing farmers' practices (2 sprays of clodinafop at 45 and 65 DAS). At the second site,compared to clodinafop with pendimethalin, mesosulfuron + iodosulfuron, fenoxaprop + metribuzin or sulfosulfuron resulted into higher yield with effective weed control efficiency. Highest yield was recorded with spray of mesosulfuron + iodosulfuron (5.1 t/ha) which was statistically at par with pendimethalin (5.06 t/ha), fenoxaprop+ metribuzin (5.01 t/ha) and sulfosulfuron at 15 DAS (4.98 t/ha).

INTRODUCTION

Wheat (*Triticum* aestivum L.) is an important cereal crop in India. This crop has competition with several grassy and broad-leaf weeds during its growth period depending upon the adopted agronomic practices, soil types, underground water quality, weed control techniques and cropping system followed. *Phalaris minor* has become the most dominant weed of wheat in the rice-wheat cropping system (RWCS) in the north-western Indo-Gangetic Plains of India.

Several groups of herbicides with different mode of action have been evuaulated and recommended after evolution of resistance in *P. minor* biotypes against isoprotouron. The herbicides, *viz.* clodinafop, sulfosulfuron and fenoxaprop were recommended to control isoproturon resistant population of *P. minor* during1997-98. These herbicides provided effective control of this weed up to 2007 (Chhokar and Sharma 2008) and improved the productivity of wheat. However, due to the continuous use of these herbicides, *P. minor* also evolved resistance against them (Dhawan *et al.* 2009). Presently, its control has become even more difficult after it evolved multiple herbicide resistance to recommended herbicides: diclofop-methyl, fenoxaprop-p-ethyl, clodinafop-propargyl, pinoxaden (ACCase); sulfosulfuron and pre-mix of mesosulfuron + iodosulfuron (ALS inhibitors); mediated by enhanced metabolism and target site mutations (Dhawan *et al.* 2012). This multiple herbicide resistant populations of *P. minor* in wheat in RWCS was again threatened wheat productivity and profitability. During surveys and meeting with farmers, it was reported that the herbicide resistance in weeds evolved due to non following of herbicide rotation, wrong time and method of herbicide application. If one herbicide stops working, farmers only change the brand, not the group of the herbicides. This indicated the need for intervention of herbicides with different mode of action in the rotation or sequential application for control of complex weed flora in wheat.

Tank-mix or pre-mix use of different herbicide chemistries or sequential application of pre- and post-emergence herbicides at different times showed effective weed control (Baghestani *et al.* 2008). Hence, the present investigation was carried out to evaluate the efficacy of pre- and post-emergence herbicides and their combination against *P. minor*, and also on productivity and profitability of wheat.

MATERIALS AND METHODS

To control the *Phalaris minor* in wheat, two farmers' participatory field experiments were conducted in winter season during the year 2015-16 and 2016-17 in the villages Makowal (Site-1) and Mallu Nangal (Site-2) of Amritsar District, Punjab. Before conducting these experiments, a survey was conducted in which 50 farmers are interviewed for the different aspects of weed control in wheat. On the basis of this survey, two different scenarios were selected. In the first scenario, farmers were using wrong time of application with wrong dose of herbicide and in the second scenario, farmers were using same group of herbicide from last five years. Farmers of these blocks were selected as the mixing of herbicides and two sprays of same herbicides was very common scene. But the wrong mixing of herbicides was harming the wheat crop. So farmers were guided to choose the compatible herbicides with right dose for getting the good results. The detail of the treatments has been given below:

Site 1: Affected with clodinafop resistance in *P. minor*

Seven different treatments *i.e*. Pendimethalin pre-emergence (PE) at 0.75 kg/ha, pendimethalin PE *fb* clodinafop post-emergence (PoE) at 0.75 kg + 0.06 kg/ha, clodinafop at 30 DAS at 0.06 kg/ha, two sprays of clodinafop at 45 and 65 DAS at 0.06 + 0.06 kg/ha, clodinafop + metribuzin (PoE tank mix) 0.06 + 0.123 kg/ha, weed free and weedy check were replicated three times.

Site 2: Herbicide rotation is not followed

Eight different treatments, *viz*. pendimethalin PE 0.75 kg/ha, pendimethalin (PE) *fb* mesosulfuron + idosulfuron (PoE) 0.75kg + 0.0144 kg/ha, sulfosulfuron (PoE) at 15 DAS 0.025 kg/ha), fenoxaprop +metribuzin (PoE) 0.1 kg/ha, clodinafop applied twice at 45 and 65 DAS 0.06 + 0.06 kg/ha, clodinafop +metribuzin (PoE tank mix) 0.06 +0.123 kg/ha, weed free and weedy check were replicated thrice.

The experiments were laid out in randomized complete block design with a plot size of 20 x 8 m. Small untreated plots (5 x 5 m)were also maintained during both the years in which herbicides were not sprayed. In both the years and both sites, wheat cultivar '*HD 2967*' was sown with seed rate 100 kg/ha at 22.5 cm spacing. All the herbicides were sprayed with battery operated knapsack sprayer fitted with flat fan nozzle using spray volume of 375 l/ha at 40 psi pressure. The data on weed density were recorded by placing 1.0 x 1.0 m quadrant at two places randomly per plot at harvest and were subjected to square root transformation before statistical analysis. Weed count data were taken after herbicide spray at 65 DAS. Weed control efficiency was calculated as given below:

$$\text{Weed control efficiency (\%)} = \frac{\text{weed count in control plot-} \\ \text{weed count in treatment plot}}{\text{weed count in control plot}} \times 100$$

The data were analyzed by using standard statistical procedures and comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

Survey data showed the trend of weed management practices at both experimental sites

Table 1. Survey data on herbicidal use at two locations in wheat in Amritsar district of Punjab, India

Particulars	2015-16 (% farmers)	
	Makowal	Mallu Nangal
Dose of herbicide use		
- Application at recommended dose	24	20
- Application at lower than	-	-
recommended dose	76	80
- Application at higher than recommended dose		
Herbicide use from last five years		
- Clodinafop	64	44
- Sulfosulfuron+ metsulfuron	10	10
- Sulfosulfuron	-	26
- Metribuzin	26	22
- Fenoxaprop	-	-
- Mesosulfuron+iodosulfuron	-	-
- Pendimethalin	-	-
Crop Rotation		
- Rice-wheat	100	100
- other	-	-
Application time		
- Application at recommended time	34	26
- Application after recommended time	66	74
Type of nozzle use		
- Flat fan	24	22
- Flood- zet	14	26
- Hollow cone	42	52
Type of spray pump		
- Power operated knap-sack spray	70	96
pump	30	4
- Manual operated spray pump		
Quantity of water used for herbicide		
spray	50	46
- 200l/ha	34	36
- 225l/ha	16	18
- 300l/ha	-	-
- 375l/ha		

(**Table 1**). Farmers used 76 to 80% higher dose of herbicide than the recommended dose, which led to development of resistance in *P. minor*. This practice was also coupled with delayed spraying time (66% at village Makowal and 74% at village Mallu Nangal) and use of hallow cone nozzle (42-52%). Less use of water for herbicide spray could also be another reason for poor control and phototoxic effect of herbicide on the crop as no farmer at both the sites used the recommended quantity of water. Continuous use of one herbicide from many years was the major reason for the resistance in *P. minor*. Clodinafop followed by the metribuzin was the favorite choice of the farmers. None of the farmer used pre-emergence herbicide (pendimethalin) and other group of herbicide like fenoxaprop, mesosulfuron + iodosulfuron. Sulfosulfuron + metsulfuron was the choice of only 10% farmers at both sites. Unrecommended herbicide metribuzin was used by 22-26% of the farmers, but it caused toxicity in the wheat crop.

At Site-1 (**Table 2**), it was found that the sequential application of pre-emergence herbicide pedimethalin at 0.75 kg/ha followed by post-emergence application of clodinafop at 0.06 kg/ha had good control on *P. minor* (77.7%) and it was at par with single spray of pre-emergence herbicide (68.3%). The sequential application of pre- and post-emergence herbicide treatment had significantly higher yield (5.33 t/ha) over the farmers' practice (two sprays of clodinafop at 45 and 60 DAS and tank mix application of clodinafop + metribuzin 4.23 and 4.8 t/ha respectively). Pre-emergence application of pendimethalin had no significant higher yield (7.1 %) over the tank mix application of unrecommended herbicides clodinafop + metribuzin though it had 70.8% weed control efficiency but the grain yield was lower due to the toxicity on the crop. The results

Table 2. Effect of different weed control treatments on weeds and grain yield of wheat (pooled data of 2015-16 and 2016-17) at site I

Treatment	Dose (kg/ha)	*P. minor* count at 65 DAS (m^2)	Dry weight of *P. minor* at harvest (g/m^2)	Weed control efficiency (%)	Grain yield (t/ha)
Pendimethalin PE	0.75	3.68(12.7)	4.46(19.0)	68.3	5.17
Pendimethalin (PE) *fb* clodinafop (PoE)	0.75+0.06	3.31(10.0)	3.78(13.3)	77.7	5.33
Clodinafop at 30 DAS	0.06	4.27(17.3)	5.05(25.0)	58.7	4.46
Two sprays of clodinafop at 45 and 65 DAS (Farmers' practice)	0.06+0.06	4.02(15.3)	5.96(35.0)	42.8	4.23
Clodinafo+metribuzin (PoE tank mix) (Farmers' practice)	0.06 +0.123	3.68(12.7)	4.31(17.7)	70.8	4.80
Weed free	-	1.0(0)	1.0(0)	100	5.46
Weedy	-	5.67(31.0)	7.83(60.7)	0	2.80
LSD (p=0.05)	-	0.55	0.82	11.9	0.38

PE: Pre-emergence, PoE: Post-emergence, *fb*: followed by; Figures in the parentheses are means of original values subjected of square root transformation $(\sqrt{x+1})$

Table 3. Effect of different weed control treatments on weeds and grain yield of wheat (pooled data of 2015-16 and 2016-17) at site II

Treatment	Dose (kg/ha)	Counts of *P. minor* at 65 DAS (m^2)	Dry weight of *P. minor* (g/m^2) at harvest	Weed control efficiency (%)	Grain yield (t/ha)
Pendimethalin PE	0.75	3.35(10.3)	4.71(21.3)	70.9	5.06
Mesosulfuron+iodosulfuron (PoE)	0.75 +0.0144	3.18(9.33)	4.20(17.0)	76.8	5.10
Sulfosulfuron (PoE) at 15 DAS	0.025	3.5(11.33)	4.61(20.3)	72.7	4.98
Fenoxaprop +metribuzin (PoE)	0.1	3.46(11.0)	4.75(21.6)	70.9	5.01
Clodinafop (PoE)	0.06	4.11(16.0)	5.90(34.0)	54.5	4.37
Clodinafop +metribuzin (PoE tank mix)	0.06 +0.123	3.49(11.33)	5.24(26.7)	64.3	4.47
Weed free	-	1.0(0)	1.00(0)	100.0	5.23
Weedy	-	5.9(34.0)	8.70(75.0)	0.00	2.83
LSD (p=0.05)	-	0.63	0.78	8.56	0.42

PE: Pre-emergence, PoE: Post-emergence, *fb*: followed by; Figures in the parentheses are means of original values subjected of square root transformation $(\sqrt{x+1})$

of Kaur *et al* (2017) also support this study. So the sequential application of pre-emergence followed by post-emergence herbicide proved effective.

Similarly at Site-2 (**Table 3**), herbicidal combination proved effective for controlling the *P. minor*. Pre-emergence application of pendimethalin, post-emergence application of mesosulfuron + iodosulfuron and fenoxaprop + metribuzin and sulfosulfuron at 15 DAS being at par with each other resulted in higher values of weed control efficiency and grain yields over the farmers' practices *i.e*. application of clodinafop or tank mix clodinafop + metribuzin. These results are in conformity with the earlier findings by Punia *et al.* (2017).

It was concluded that for the effective weed control and to manage resistance in *Phalaris minor* sequential application of pre-emergence followed by post-emergence herbicides was a good option. Similarly the herbicidal rotation of mesosulfuron + iodosulfuron and fenoxaprop + metribuzin and sulfosulfuron at 15 DAS proved good control over the *Phalaris minor.*

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Weed dynamics in conservation agricultural systems as influenced by conservation tillage and nutrient management practices under rainfed finger millet

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ABSTRACT

Weeds are major threats for loss of yield in any cropping system. Especially in conservation tillage systems, it is a basic necessary requirement to keep the weed population below their threshold levels to realize optimum grain yields. Managing weeds in conservation tillage systems are very essential to optimize crop production. Hence, to study the effect of conservation tillage practices on weed dynamics, soil weed seed bank and their distribution, a field experiment was conducted under rainfed finger millet (*Eleusine coracana* (L.) Gaertn.) on *Alfisols* for two consecutive seasons during 2014 and 2015 at All India Coordinated Research Project on Dryland Agriculture, University of Agricultural Sciences, GKVK, Bengaluru, India under split-plot design with three main plots (different tillages) and five sub-plots (different nutrient management). Conventional tillage has recorded significantly higher grain and straw yield of finger millet (3.04 and 4.69 t/ha, respectively) due to effective control of weeds as evidenced by lower total weed density and dry weight observed (13.7 no./m^2, 8.0 g/m^2 at 30 DAS and 23.9 no./m^2, 9.0 g/m^2 at 60 DAS) along with higher weed control efficiency (92.5-93.2% in 2014 and 93.3-93.8% in 2015) and lower weed index (7.6-10.3%) due to lower number of weed seeds observed during 2014 (12.3, 19.5 and 4.6/kg soil at 15, 30 and 60 days, respectively) and 2015 (11.3, 17.6 and 4.1/kg soil at 15, 30 and 60 days, respectively as compared to minimum tillage (2.60 and 4.03 t/ha, respectively). Whereas, zero tillage has recorded significantly lower grain and straw yield (2.09 and 3.24 t/ha, respectively) due to poor weed control as observed by higher soil weed seed bank. Among different nutrient management practices application of 100% recommended NPK + 7.5 t FYM/ha yielded significantly higher grain and straw yields (3.03 and 4.68 t/ha, respectively) over other nutrient management practices. Wherein, the soil weed seed bank was not significantly influenced by nutrient management practices and their interactions with the tillage.

INTRODUCTION

Conservation agriculture practices are gaining a lot of importance across the globe due to their various advantages over conventional agricultural practices. These conservation agricultural practices serve as an alternative strategy to sustain agricultural production due to the growing resource degradation problems, particularly under rainfed conditions. These rainfed systems are characterized by low and unstable yields, vulnerable to erratic rainfall, prone to frequent droughts amidst the declining natural resource base. Hence the conservation of soil, water and other natural resources is a crucial factor for achieving sustainable production in rainfed farming. Whereas, the weed menace is very high under conservation tillage systems such as minimum and zero tillages due to less intense tillage practices. This higher weed menace under less intense tillage practices is attributed to continuous deposition of weed seeds in the top soil layer due to no soil disturbance which eventually emerge as the congenial conditions prevail and compete with the crops. Managing weed population below the economic threshold level is the basic need to optimize the productivity in any cropping systems especially in conservation tillage systems.

The weed emergence is directly proportional to the number of viable weed seeds present in soil called as 'soil weed seed bank', which are reserves of viable seeds present on the surface and in the soil containing new seeds recently shed by weed plants as well as older seeds that have persisted in the soil for several years. Thus, the weed seed bank is an indicator of past and present weed populations in soil and is the main source of weeds in agricultural fields. Management of weeds in a particular area would require prior information on weed seed bank which really helps in designing weed management practices related to a particular micro-climate in an area. As tillage influences the vertical distribution of weed seeds in soil layer and weed diversity, no-till cropping systems leave most seeds in top 1.0 cm layer of the soil profile (Yenish *et al.* 1992). The differential distribution of seeds in the soil profile subsequently leads to change in weed population dynamics.

Finger millet (*Eleusine coracana* (L.) Gaertn.) belongs to family Poaceae (subfamily: Chloridoideae) widely grown as millet in the arid regions of Africa and Asia (India and Nepal). The most striking feature, which made finger millet an important dryland crop is, its resilience and ability to withstand adverse weather conditions when grown in soils having poor water holding capacity. It is a predominant food crop of the Southern part of Karnataka, mainly grown under rainfed conditions in *Alfisols* in India. Globally innovations of conservation agriculture-based crop management technologies are said to be more efficient, use fewer inputs, improve production and income, and address the emerging problems (Gupta and Seth 2007). An undeniable and expensive consequence of agricultural practices in the management of weeds in agricultural systems as the weeds are responsible for significant crop yield and financial losses in agricultural production in the order of 10 per cent per year worldwide (Oerke 2006). With these backgrounds, this study was conducted to study the weed dynamics, soil weed seed bank and their distribution as influenced by conservation tillage and nutrient management practices under rainfed finger millet (*Eleusine coracana* (L.) Gaertn.) on *Alfisols* at Eastern Dry Zone of Karnataka in India.

MATERIAL AND METHODS

A field experiment was carried out to study the weed dynamics, soil weed seed bank and their distribution on *Alfisols* as influenced by conservation tillage and nutrient management practices under rainfed finger millet (*Eleusine coracana* (L.) Gaertn.) in two consecutive seasons at *Kharif* 2014 and 2015 at All India Coordinated Research Project on Dryland Agriculture, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bengaluru (India). The experimental site was located at the Eastern Dry Zone of Karnataka at a latitude of $12^0$58' N and longitude of $75^0$35' E at an altitude of 930 m above mean sea level. The soil type of the experimental site belongs to Vijayapura series and represents the typical lateritic area of Bengaluru plateau. These soils were classified as fine, kaolinitic, isohyperthermic, Typic Kandiustalf as per USDA classification. These soils were deep, yellowish red, lateritic, red sandy clay loam with good drainage and were derived from granite-gneiss under subtropical semi-arid climate. The texture of soil was red sandy clay loam (33.2% coarse sand, 36.4% fine sand, 7.00% silt and 23.0% clay). The soils were acidic, lower in organic carbon, available nitrogen, potassium and medium in available phosphorous.

The experiment was conducted under split-plot design with three tillage treatments as main plots, *viz.* Conventional tillage [2 ploughings + 1 harrowing + 2 inter cultivation at 25 and 50 days after sowing (DAS)] with drill sown finger millet, minimum tillage (1 ploughing + 1 harrowing + application of pre-emergence herbicide - isoproturon 75 WP at 565 g/ha) - drill sown finger millet and zero tillage (glyphosate 41 SL at 10 ml/l at 15 days before transplanting) with transplanted finger millet at 25 DAS and five nutrient management treatments as sub-plots, *viz.* 100 % recommended NPK (50:40:25 kg NPK/ha), 100% recommended NPK + 7.5 t FYM/ha, horsegram residue mulch + 100% recommended NPK, horsegram residue mulch + 50% recommended NPK + 25% N through FYM + *Azotobacter* seed treatment and horsegram residue mulch + fertilizers based on soil test results and are replicated thrice. In both the seasons, the soil was found low in available N, K, and medium in available P, hence 130% N, K and 100% recommended P were applied in N_5 treatment.

The pre-emergence herbicide isoproturon 75 WP at 565 g/ha was applied in minimum tillage plots two DAS using knapsack sprayer with WFN 78 nozzle with a spray volume of 750 l/ha. The post-emergence herbicide glyphosate was applied in the zero tillage plots at 15 days before transplanting *i.e.*, glyphosate 41 SL at 10 ml/l using knapsack sprayer with WFN 40 nozzle with a spray volume of 500 l/ha at the active green stage of weeds. The ploughing and harrowing operations were done using tractor-drawn cultivator and disc harrow, respectively and inter cultivations were done using blade hoe at 25 and 50 DAS using bullock pair as per the treatments in respective plots. The finger millet variety '*GPU-28'* was sown/transplanted at a spacing of 30 x 10 cm with a seed rate of 10 kg/ha on 9th August, during 2014 and 10th August during 2015. On the same date of sowing of finger millet in the main field, the sowing of seeds in the nursery was also done and seedlings were transplanted at 25 DAS to the main field after giving light irrigation (5 mm) to overcome the transplanting shock. The fertilizer sources used were urea, DAP and MOP. 50% of recommended nitrogen and entire phosphorus and potassium were given as basal dose at the time of sowing and remaining 50% of nitrogen was applied as a top dress at 30 DAS. The horsegram (*Dolichos biflorus* L.) seeds (variety '*PHG-9*') were broadcasted at 50 kg/ha in the first fortnight of May with pre-monsoon rains in respective treatment plots for mulching and harvested at 60 DAS and was mulched in between complete established finger millet crop rows (During the first year of experiment *i. e.,* 2014, the average quantity of 970 kg/ha dry horsegram biomass was harvested and was applied uniformly in all mulched plots. During 2015, the amount of horsegram biomass generated from individual treatment plots was applied to their respective plots *i. e.,* horsegram residue mulch + 100 % recommended NPK – 1038 kg/ha, horsegram residue mulch + 50% recommended NPK + 25% N through FYM + *Azotobacter* seed treatment – 948 kg/ha, horsegram residue mulch + fertilizers based on soil test results – 1159 kg/ha, and the composition of horsegram biomass was 0.50% N, 0.15% P and 0.39% K. The seeds were treated with *Azotobacter* nitrogen-fixing biofertilizer and while transplanting, the root dipping of seedlings was done as per the treatments. The calculated amount of farm yard manure was incorporated into the soil fifteen days before sowing. The FYM on N basis was applied by considering the N content of FYM *i.e.,* 0.50% (The composition of FYM was 0.50% N, 0.21% P and 0.50% K). In places where the finger millet seeds were failed to germinate and excess populations, the gap filling and thinning were done, respectively at 15 DAS to maintain optimum plant population and intra row spacing.

The total amount of rainfall received was more than normal in both the years with 994.5 mm during 2014 and 1070.5 mm during 2015. The crop growth period was from May to December in both the seasons (horsegram-finger millet). The previous crop grown at the experimental site was finger millet + pigeonpea intercropping during *Kharif* 2013 and left fallow during *Rabi* and Summer. During the second season of the experiment, due to the long dry spell, protective irrigation (10.2 mm) was given on 27-10-2015. For weed observations from the field, a quadrant of 0.5 × 0.5 m was selected in each treatment at random for recording weed count at two spots per plot and expressed as number/m^2 and averaged over two random spots per plot at 30 and 60 DAS. Out of two random spots per plot, one of the sampled spot was selected for recording weed dry weight and were dried in hot air oven at 65ºC, till constant dry weight was recorded. The dry weight of weeds was expressed as g/m^2.

For the weed seed bank experiment, the experiment was conducted using factorial CRD design with 45 treatment combinations (3 main plot tillage treatment x 5 nutrient management practices x 3 soil depths) and three replications. The weed seed distribution in the soils of the experimental site was studied at different depths through plastic tray culture experiments in the shade house. Soil samples were collected from the experimental site after harvest of finger millet at three different depths *i.e.,* 0-10, 10-20 and 20-30 cm and dried under shade. One kg of soil from each depth was weighed and kept in the plastic pots containing holes at bottom side in all the four corners to study the emerged weeds present in the soil. The pots were watered manually as and when needed to maintain adequate moisture. After germination, the weed seedlings were identified, counted and removed and again soil was thoroughly stirred and watered regularly for another flush of weeds. The cycle of operation was repeated till all the weed seeds were exhausted. Later the original values of weed density, dry weight and soil weed seed bank were subjected to suitable transformations (square root or logarithmic) depending on the variation in the data and subjected to statistical analysis.

The weed control efficiency was worked out using the formula as suggested by Mani *et al.* (1973) and weed index was worked out by using the formula given by Gill and Kumar (1969). The crop was harvested on 12-12-2014 during the first season and on 03-12-2015 during the second season of the experiment. The grain and straw weight were recorded and were converted into kg/ha.

The nitrogen content in weed samples was estimated by Micro Kjeldhal method (Jackson 1967). Whereas, the phosphorus and potassium were digested in di-acid mixture (900 ml conc. HNO_3 + 400 ml of per chloric acid) as described by Piper (1966) and the phosphorus content of the di-acid digested grain and straw samples was determined by Vanado molybdo phosphoric yellow colour method (Jackson 1967) and the potassium content in weed samples was determined by flame photometer method as described by Jackson (1967) and expressed in percentage on dry weight basis. The percentage concentration of these nutrients was multiplied with biomass of weeds to get the total nutrient uptake by weeds (kg/ha).

The experimental data on weed data, nutrient uptake, the yield of finger millet *etc.* were subjected to Fisher's method of "Analysis of variance" (ANOVA) as outlined by Gomez and Gomez (1984). The pooled analysis was also done using two season's data. The emphasis was given to present the results of the pooled data instead of the individual season/year wise as a similar trend was observed in both the seasons/ years of the field experiment. Whenever F-test was significant for comparison amongst the treatment means, an appropriate value of least significant differences (LSD) was worked out. Otherwise against LSD values, abbreviation NS (Non-Significant) was indicated. All the data were analyzed and the results were presented and discussed at a probability level of 0.05 percent and correlation study was done as given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed flora

The different weed species found during experimental period in finger millet crop up to initial 60 DAS were *Cyperus rotundus* (L.) among sedges, *Digitaria marginata* (L.), *Cynodon dactylon* (L.), *Eleusine indica* (L.) among grasses and *Borreria hispida* (L.), *Portulaca oleracea* (L.), *Mimosa pudica* (L.), *Phyllanthus niruri* (L.), *Euphorbia geniculata* (O.), *Commelina benghalensis* (L.), *Chenopodium album* (L.) among broad-leaved weeds. Among sedges, *Cyperus rotundus* (L.) and among broad-leaved weeds, *Borreria hispida* (L.) were dominant. Among grasses, all the weeds were more or less equally found dominant. At later stages, other weeds species found were *Cyperus iria* (L.), *Dactyloctenium aegyptium* (L.), *Chloris barbata* (Sw.), *Panicum repens* (L.), *Ageratum conyzoides* (Orteg.), *Euphorbia geniculata* (O.), *Cleome monophylla* (L.), *Achyranthus aspera* (L.), *Amaranthus viridis* (Hook. F.), and *Acanthospermum hispidum* (DC.). The emergence of different weed species was attributed to soil weed seed bank, difference in tillage intensity, earlier cropping system, weather parameters, congeniality of soil environment *etc*. Changing tillage regimes changes the disturbance frequency of the farm field and crop management strongly influences weed communities and a change in tillage is expected to have a pronounced effect on the weed community and results in a diversity of weed species (Boscutti *et al.* 2015 and Nichols *et al.* 2015).

Weed density and dry weight

The density of weeds was significantly influenced by the different tillage practices in finger millet (**Table 1**). Among different tillage practices, conventional tillage [(2 ploughings + 1 harrowing + 2 inter cultivations) – sowing] recorded significantly lower density and dry weight of weeds at 30 DAS (13.7 no./m^2 and 8.0 g/m^2, respectively) and 60 DAS (23.9 no./m^2 and 9.0 g/m^2, respectively) as compared to minimum tillage [(1 ploughing + 1 harrowing + pre-emergence herbicide spray) - sowing)] at 30 DAS (40.0 no./m^2 and 30.2 g/m^2, respectively) and 60 DAS (73.2 no./m^2 and 22.2 g/m^2, respectively). While significantly higher weed density and dry weight were observed under zero tillage **(**blanket herbicide spray) **-** transplanting at 30 DAS (97.4 no./ m^2 and 64.8 g/m^2, respectively) and 60 DAS (199.0 no./m^2 and 67.6 g/m^2, respectively). There was no significant difference observed among different nutrient management practices and their interactions with the tillage at different crop growth stages of finger millet for density as well as the dry weight of weeds.

The lower weed density and dry weight in conventional tillage were because of inversion of soil by ploughing and subsequent inter cultivation at 25 and 50 DAS which removed germinated weeds and helped in physical suppression of weeds. Nichols *et al.* (2015) quoted that tillage kill live weeds before they reproduce, thus preventing seed production and it is a useful tool for controlling established weed population, curtailing the weed seed bank and weed intensities. Minimum tillage has recorded comparatively better weed control next to conventional tillage because of translocation of soil-applied pre-emergence isoproturon 75 WP herbicide at 565 g/ha into the foliage which turns green leaves into light green coloured leaves followed by burning of leaf tips, chlorosis, growth retardation and eventually death of plants due to the interference of isoproturon with the reducing side of PS-II (Radosevich *et al.* 1979). Whereas, significantly higher weed density and dry weight under zero tillage were due to the deposition of weed seeds in the top layer itself due to no soil inversion and soil disturbance and more number of weeds from the previous seasons. These seeds remain viable and germinate whenever they get congenial conditions. Romaneckas *et al.* (2009) witnessed more weed infestation in zero tillage than conventional and minimum tillage systems. Subbulakshmi *et al.* (2009) reported that zero tillage resulted in the deposition of more seeds and propagules of predominant annual and perennial weeds near the soil surface.

Table 1. Total weed density and dry weight in finger millet at 30 and 60 DAS as influenced by tillage and nutrient management practices

Treatment	Weed density (no./m^2)						Weed dry weight (g/m^2)					
	30 DAS#			60 DAS#			30 DAS#			60 DAS#		
	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
Tillage practice												
Conventional tillage- Sowing	1.06 (13.2)	1.21 (14.1)	1.19 (13.7)	1.22 (21.3)	1.45 (26.5)	1.40 (23.9)	0.92 (8.2)	0.98 (7.7)	0.99 (8.0)	1.00 (9.2)	1.03 (8.79)	1.04 (9.02)
Minimum tillage- Sowing	1.65 (43.3)	1.58 (36.8)	1.62 (40.0)	1.84 (69.8)	1.89 (76.7)	1.87 (73.2)	1.50 (30.4)	1.49 (30.1)	1.49 (30.2)	1.35 (22.3)	1.37 (22.2)	1.38 (22.2)
Zero tillage-Transplanting	1.95 (93.7)	2.01 (101.2)	1.99 (97.4)	2.24 (185.7)	2.31 (212.3)	2.28 (199.0)	1.78 (63.4)	1.82 (66.1)	1.81 (64.8)	1.76 (57.5)	1.89 (77.7)	1.82 (67.6)
LSD (p=0.05)	0.28	0.24	0.25	0.32	0.34	0.33	0.24	0.21	0.05	0.15	0.11	0.12
Nutrient management practice												
100 % recommended NPK (50:40:25 kg NPK/ha)	1.60 (51.7)	1.64 (51.9)	1.61 (52.4)	1.82 (94.7)	1.89 (108.8)	1.87 (105.3)	1.44 (34.5)	1.45 (36.1)	1.45 (37.5)	1.42 (30.6)	1.44 (38.2)	1.43 (36.0)
100% recommended NPK + 7.5 t FYM/ha	1.71 (60.0)	1.63 (53.7)	1.64 (54.4)	1.94 (109.3)	1.94 (114.2)	1.92 (107.4)	1.54 (40.6)	1.47 (38.8)	1.49 (38.7)	1.48 (35.1)	1.48 (39.5)	1.47 (36.6)
Horsegram residue mulch + 100 % recommended NPK	1.45 (41.7)	1.58 (48.5)	1.57 (47.4)	1.65 (77.3)	1.85 (96.3)	1.80 (87.4)	1.32 (28.6)	1.40 (31.7)	1.39 (30.6)	1.29 (24.8)	1.40 (33.2)	1.37 (29.6)
Horsegram residue mulch + 50 % recommended NPK + 25 % N through FYM + *Azotobacter* seed treatment	1.54 (48.9)	1.59 (49.8)	1.59 (49.2)	1.76 (90.5)	1.87 (99.1)	1.83 (91.4)	1.39 (33.4)	1.42 (33.0)	1.42 (32.6)	1.37 (29.8)	1.42 (34.6)	1.40 (31.4)
Horsegram residue mulch + Fertilizers based on soil test results	1.46 (48.0)	1.59 (49.7)	1.58 (48.5)	1.67 (89.4)	1.87 (107.3)	1.85 (100.0)	1.32 (32.9)	1.41 (33.7)	1.41 (32.2)	1.28 (28.0)	1.41 (35.7)	1.39 (31.3)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

DAS-Days after sowing, # $\sqrt{x+2}$ transformation, Figures in parentheses indicate original values, DAS-Days after sowing, NS-Non significant

Wherein, there was no significant difference between sub-plot nutrient management due to the absence of weed management procedures under sub-plots.

Weed control efficiency and weed index

The crop yield is directly proportional to weed control efficiency (WCE) and inversely related to weed index (WI) in any crop. Conventional tillage in finger millet has attained higher WCE at 30 DAS (92.5 to 93.2%) and 60 DAS (93.3 to 93.8%) as compared to minimum and zero tillage **(Table 2)**. And the lowest weed index was observed under conventional tillage (10.26 and 7.56% in 2014 and 2015, respectively) as compared to that of minimum tillage (22.70 and 21.27% in 2014 and 2015, respectively) and zero tillage (35.49 and 39.82% in 2014 and 2015, respectively). The WI indicates the percent yield loss caused due to the presence of weeds than weed-free conditions. Hence, the lower weed index and higher weed control efficiency in conventional tillage were attributed to a lower loss in crop yields due to lower weed competition as indicated by lower total weed density and dry weight (**Table 1**) at 30 and 60 DAS as compared to minimum and zero tillage. The WCE was increased from 2014 to 2015 in conventional tillage and minimum tillage due to their reduction in total weed dry weight from 2014 to 2015. Whereas in zero tillage, the WCE was lowered from 2014 to 2015 due to increased total weed dry weight due to increased soil weed seed bank from 2014 to 2015. Subbulakshmi *et al*. (2009) who recorded a higher weed index under zero tillage in maize-sunflower cropping system due to the higher weed density and dry weight in zero tillage.

Nutrient uptake by weeds

Weeds are the major competitors for the absorption of nutrients in the crop fields. Therefore appropriate measures have to be taken to manage the weeds to grab satisfactory crop yields. Among different tillage practices, conventional tillage has shown significantly lower uptake of nutrients (7.9, 6.0 and 12.8 kg N, P and K/ha, respectively) by weeds as compared to minimum tillage (14.8, 11.6 and 24.1 kg N, P and K/ha, respectively) and zero tillage (22.2, 16.7 and 34.8 kg N, P and K/ha, respectively). Whereas, the various nutrient management practices and their interactions with tillage were not significantly different for nutrient uptake by weeds **(Table 3)**. The lowest uptake of N, P and K by weeds in conventional tillage was an indication of lower weed dry weight at harvest due to effective weed control as indicated by lowest weed density. As the nutrient uptake by weeds and grain yields are negatively correlated (-0.781, -0.778 and -0.778 for N, P and K uptake by weeds with the grain yield) (**Table 4**), the lower nutrient uptake by weeds in conventional tillage has paved the way for higher nutrient uptake by crop, leading to higher grain yield.

Table 2. Weed control efficiency at different crop growth stages and weed index in finger millet as influenced by different tillage practices

Treatment	Weed control efficiency (%)				Weed index (%)	
	30 DAS		60 DAS			
	2014	2015	2014	2015	2014	2015
Tillage practice						
Conventional tillage- sowing	92.5	93.2	93.3	93.8	10.26	7.56
Minimum tillage- sowing	72.5	73.1	83.8	84.3	22.70	21.27
Zero tillage-transplanting	42.5	41.0	58.2	45.0	35.49	39.82

DAS-Days after sowing, The data on total weed dry weight in control (110.3 and 137.6 g/m^2 at 30 DAS and 60 DAS for 2014 and 112.1 and 141.5 g/m^2 at 30 DAS and 60 DAS, for 2015 for calculating WCE were taken from additionally maintained plots in the experimental area with normal package of practices. The data on grain yields under weed free conditions (3568 kg/ha for 2014 and 3115 kg/ha for 2015) for calculating WI were taken from additionally maintained plots in the experimental area.

Whereas in zero tillage, the higher nutrient uptake by weeds was attributed to their higher weed biomass. These findings are supported by Monsefi *et al.* (2016) who reported the highest uptake of N, P and K by weeds in zero tillage-raised bed system as compared to the conventional tillage-raised-bed system.

Yield of finger millet

The grain and straw yield of finger millet was significantly influenced by different conservation tillage and nutrient management practices. Conventional tillage has recorded significantly higher grain and straw yield of finger millet (3.04 and 4.69 t/ha, respectively) which is evidenced by lower weed index (10.26 and 7.56% in 2014 and 2015, respectively) as compared to minimum tillage (2.60 and 4.03 t/ha, respectively) **(Table 3)**. Whereas, zero tillage has recorded significantly lower grain and straw yield (2.09 and 3.24 t/ha, respectively). Among different nutrient management practices, application of 100 % recommended NPK + 7.5 t FYM/ha has realized significantly higher grain and straw yield of finger millet (3.03 and 4.68 t/ha, respectively) followed by horsegram residue mulch + fertilizers based on soil test results (2.70 and 4.17 t/ha, respectively) which was found on par with horsegram residue mulch + 100% recommended NPK (2.61 t/ha and 4.03 t/ha, respectively) as compared to 100% recommended NPK alone (2.32 and 3.58 t/ha, respectively). Wherein, significantly lower grain and straw yield were observed in horsegram residue mulch + 50% recommended NPK + 25% N through FYM + *Azotobacter* seed treatment (2.24 and 3.45 t/ha, respectively). The higher grain and straw yield of finger millet in conventional tillage was attributed to significantly lower total weed density and dry weight at 30 and 60 DAS due to effective control of weeds **(Table 1)** with tillage and inter cultivation. The lower grain yield in zero tillage was due to higher weed competition which was

Table 3. Nutrient uptake by weeds at harvest and yield of finger millet as influenced by tillage and nutrient management practices

Treatment	Nitrogen (kg/ha)			Phosphorus (kg P/ha)			Potassium (kg K/ha)			Grain yield (t/ha)			Straw yield (t/ha)		
	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
Tillage practice															
Conventional tillage- Sowing	8.0	7.8	7.9	6.3	5.7	6.0	13.2	12.5	12.8	3.20	2.88	3.04	4.95	4.42	4.69
Minimum tillage- Sowing	14.9	14.7	14.8	11.7	11.4	11.6	24.4	23.9	24.1	2.76	2.45	2.60	4.29	3.76	4.03
Zero tillage-Transplanting	22.0	22.5	22.2	16.4	16.9	16.7	34.5	35.1	34.8	2.30	1.87	2.09	3.61	2.87	3.24
LSD (p=0.05)	1.6	1.5	0.9	1.3	1.1	0.7	2.7	2.4	1.5	0.30	0.31	0.18	0.54	0.48	0.30
Nutrient management practice															
100 % recommended NPK (50:40:25 kg NPK/ha)	15.2	15.4	15.3	11.6	11.7	11.7	24.3	24.5	24.4	2.48	2.16	2.32	3.85	3.31	3.58
100 % recommended NPK + 7.5 t FYM/ha	15.6	15.6	15.6	12.0	11.8	11.9	25.1	24.7	24.9	3.25	2.81	3.03	5.06	4.31	4.68
Horsegram residue mulch + 100 % recommended NPK	14.5	14.5	14.5	11.1	10.9	11.0	23.2	23.0	23.1	2.79	2.42	2.61	4.35	3.72	4.03
Horsegram residue mulch + 50 % recommended NPK + 25 % N through FYM + *Azotobacter* seed treatment	15.0	14.9	15.0	11.5	11.3	11.4	24.0	23.8	23.9	2.37	2.10	2.24	3.68	3.23	3.45
Horsegram residue mulch + Fertilizers based on soil test results	14.6	14.6	14.6	11.2	11.0	11.1	23.5	23.2	23.3	2.88	2.51	2.70	4.48	3.86	4.17
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.19	0.25	0.15	0.30	0.38	0.24

Note: LSD-Least Significant difference, NS-Non significant clearly expressed by lower WCE (42.5 and 41.0% during 2014 and 2015 at 30 DAS and 58.2 and 45.0% during 2014 and 2015 at 60 DAS, respectively) and higher weed index (35.49 and 39.82% in 2014 and 2015, respectively) (**Table 2**). Due to increased weed density and dry weight in zero tillage, there was increased nutrient uptake by weeds (**Table 3**) at harvest which showed the greater magnitude of weeds competition on crops. This magnitude of weed competition in terms of nutrient uptake by weeds on finger millet yield was again also revealed through regression equations (**Table 4**). These regression equations demonstrated that each one kg increase in uptake of N, P and K by weeds will reduce the finger millet grain yields by 64.90, 86.89 and 42.09 kg grains/ha because of a negative correlation between nutrient uptake by weeds and grain yield of finger millet.

This decrease in grain yield with increase in weed density and dry weight in zero tillage was strongly depicted by significantly negative correlation coefficient (**Table 4**) between yield and total weed density at 30 and 60 DAS (-0.765 and -0.747, respectively) as well as between yield and total weed dry weight at 30 and 60 DAS (-0.760 and -0.744, respectively). Further the regression equations emphasized that, increase in total weed density by 1/m^2 at 30 DAS and 60 DAS as well as increase in total weed dry weight by one g/m^2 at 30 DAS and 60 DAS will cause decrease in grain yield of finger millet by 10.67, 4.92, 15.71 and 14.39 kg/ha. These results are in accordance with Guan *et al.* (2014) and Bilalis *et al.* (2011) who quoted that zero tillage in wheat and summer maize have registered lower grain yield due to poor growth, yield attributes and poor root growth due to increased soil penetration resistance, bulk density and weed growth.

The higher yield attributes gained under 100% recommended NPK + 7.5 t FYM/ha has come from improved growth attributes because of improved nutrient availability as a consequence of sufficient and integrated nutrient supply from both inorganic and organic sources. This application of FYM has led to improvement in soil physico-chemical properties which ultimately resulted in favouring of crop growth for higher yield. Whereas, the application of horsegram residue mulch + 50% recommended NPK + 25% N through FYM + *Azotobacter* seed treatment has recorded lower yield due to poor nutrient supply.

Soil weed seed bank

The tillage practices have the profound influence on the distribution of weed seeds and seed bank size in the soil profile. In zero tillage, seeds infiltrate the soil via very slow processes (cracks, fauna, freeze-dry cycles), resulting in an accumulation of weed seeds (60–90%) in the top 5 cm of the soil (Yenish *et al.* 1992). Thus, tillage induces changes in seed distribution therefore indirectly affect the germination and seedling establishment. The weed seed bank is defined as the mature seeds that exist in the soil. At any given time, the soil seed bank contains viable weed seeds produced in several previous years (the seed bank). These seeds (consisting of different ages) will either be able to germinate when the conditions are favourable (suitable temperature, adequate water and enough oxygen) or be dormant. Among different tillage practices, conventional tillage has exhibited a lower number of grasses, sedges and broadleaf weeds (2.70 to 5.78/kg soil at 15 days, 4.54 to 8.76/kg soil at 30 days and 1.15 to 1.79/kg soil at 60 days). This was followed by minimum tillage (6.28 to 16.51/kg soil at 15 days, 9.94 to 20.57/kg soil at 30 days and 3.27 to 4.15/kg soil at 60 days) and

Table 4. Correlation and regression equations for weed density, weed dry weight, nutrient uptake by weeds and total weed seeds with grain yield of finger millet as influenced by tillage and nutrient management practices

Dependent variable (Y)	Independent variable (x)	Correlation coefficient (r)	Regression equation	R^2
Grain yield (kg/ha)	TWD at 30 DAS (no./m^2)	-0.765	Y=3116.14-10.67x	0.585
	TWD at 60 DAS (no./m^2)	-0.747	Y=3064.159-4.92x	0.559
	TWDW at 30 DAS (g/m^2)	-0.760	Y=3117.61-15.71x	0.578
	TWDW at 60 DAS (g/m^2)	-0.744	Y=3052.49-14.39x	0.554
	Total N uptake by weeds (kg/ha)	-0.781	Y=3550.51-64.90x	0.610
	Total P uptake by weeds (kg/ha)	-0.778	Y=3571.34-86.89x	0.606
	Total K uptake by weeds (kg/ha)	-0.778	Y=3585.57-42.09x	0.606
		2014		
	TWS at 15 DAS	-0.729	Y=3529.16-25.62x	0.531
	TWS at 30 DAS	-0.726	Y=3593.86-19.55x	0.527
	TWS at 60 DAS	-0.727	Y=3387.97-50.92x	0.528
		2015		
	TWS at 15 DAS	-0.829	Y=3167.85-24.03x	0.687
	TWS at 30 DAS	-0.825	Y=3241.34-19.19x	0.681
	TWS at 60 DAS	-0.828	Y=3075.182-54.92x	0.686

Note: TWD- Total weed density, TWDW- Total weed dry weight. TWS-Total weed seeds zero tillage (12.02 to 21.43/kg soil at 15 days, 18.66 to 25.25/soil at 30 days and 6.08 to 8.49/kg soil at 60 days) during 2014.

Among different depths, the top 0-10 cm soil depth has witnessed the significantly higher number of weeds (12.19 to 24.05/kg soil at 15 days, 16.44 to 29.74/kg soil at 30 days and 5.51 to 8.12/kg soil at 60 days). It was followed by 10-20 cm depth and 20-30 cm depth during 2014 **(Table 5 and 6)**. Whereas, the different nutrient management practices, the interaction of tillage and nutrient management practices, nutrient management practices and depths were found non-significant for different categories of weeds at 15, 30 and 60 days during 2014. But, the interactions of tillage and depth were significantly different for different categories of weeds. Among different interactions, 0-10 cm soil depth samples of zero tillage practice has demonstrated significantly higher number of weeds (51.41 to 36.73/kg soil at 15 days, 28.63 to 43.16/kg soil at 30 days and 9.67 to 14.56/kg soil at 60 days) followed by other interactions and significantly lowest number of weeds were observed under 20-30 cm in conventional tillage (0.33 to 1.51/kg soil at 15 days,

Table 5. Weed no./kg of soil at different days as influenced by tillage and nutrient management practices during 2014

Treatments	At 15 days				At 30 days				At 60 days			
	Sedge*	Grasses*	BLW*	Total#	Sedge*	Grasses*	BLW*	Total#	Sedge*	Grasses*	BLW*	Total*
Tillage practice												
T_1	1.86 (2.7)	2.12 (3.8)	2.52 (5.8)	1.08 (12.3)	2.30 (4.5)	2.55 (5.9)	3.02 (8.8)	1.26 (19.5)	1.44 (1.1)	1.56 (1.6)	1.62 (1.8)	2.20 (4.6)
T_2	2.62 (6.3)	3.11 (9.1)	4.07 (16.5)	1.48 (31.9)	3.26 (9.9)	3.85 (14.6)	4.52 (20.6)	1.63 (45.1)	2.03 (3.3)	2.10 (3.7)	2.21 (4.1)	3.37 (11.1)
T_3	3.50 (12.0)	3.66 (13.1)	4.61 (21.4)	1.64 (46.5)	4.37 (18.7)	4.51 (20.3)	4.99 (25.2)	1.78 (64.2)	2.62 (6.1)	2.77 (7.1)	3.01 (8.5)	4.64 (21.7)
LSD (p=0.05)	0.06	0.06	0.08	0.02	0.07	0.08	0.09	0.02	0.04	0.05	0.05	0.10
Nutrient management practice												
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depths (C)												
D_1	3.49 (12.2)	3.77 (14.1)	4.83 (24.0)	1.65 (50.4)	4.02 (16.4)	4.63 (21.9)	5.40 (29.7)	1.79 (68.0)	2.46 (5.5)	2.77 (7.2)	2.91 (8.1)	4.47 (20.9)
D_2	2.52 (5.5)	2.88 (7.4)	3.57 (12.0)	1.41 (24.9)	3.15 (9.2)	3.52 (11.6)	4.02 (15.3)	1.57 (36.4)	1.94 (2.8)	2.06 (3.3)	2.20 (3.9)	3.28 (10.1)
D_3	1.96 (3.3)	2.25 (4.5)	2.79 (7.6)	1.13 (15.5)	2.76 (7.5)	2.76 (7.4)	3.11 (9.5)	1.32 (24.4)	1.69 (2.2)	1.60 (1.8)	1.73 (2.4)	2.45 (6.4)
LSD (p=0.05)	0.06	0.06	0.08	0.02	0.07	0.08	0.09	0.02	0.04	0.05	0.05	0.10
Tillage (T) × Nutrient management practice												
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T) × Depths (C)												
T_1D_1	2.29 (4.2)	2.54 (5.4)	3.06 (8.4)	1.30 (18.1)	2.63 (5.9)	3.05 (8.3)	3.67 (12.5)	1.46 (26.7)	1.64 (1.7)	1.90 (2.6)	1.94 (2.8)	2.84 (7.0)
T_1D_2	2.12 (3.5)	2.47 (5.1)	2.91 (7.4)	1.26 (16.1)	2.66 (6.1)	2.97 (7.8)	3.49 (11.2)	1.43 (25.9)	1.65 (1.7)	1.81 (2.3)	1.88 (2.5)	2.75 (6.6)
T_1D_3	1.15 (0.3)	1.36 (0.8)	1.58 (1.5)	0.67 (2.7)	1.62 (1.6)	1.63 (1.6)	1.90 (2.6)	0.90 (5.9)	1.01 (0.0)	1.22 (0.5)	1.30 (0.7)	1.49 (1.2)
T_2D_1	3.45 (10.9)	3.97 (14.8)	5.29 (27.0)	1.74 (52.8)	3.97 (14.7)	4.93 (23.3)	5.87 (33.6)	1.87 (71.6)	2.48 (5.1)	2.73 (6.5)	2.83 (7.0)	4.43 (18.7)
T_2D_2	2.48 (5.2)	3.00 (8.0)	3.89 (14.2)	1.46 (27.4)	3.10 (8.8)	3.72 (13.0)	4.32 (17.7)	1.61 (39.4)	1.94 (2.8)	2.01 (3.0)	2.14 (3.6)	3.20 (9.5)
T_2D_3	1.92 (2.7)	2.35 (4.6)	3.03 (8.3)	1.24 (15.6)	2.70 (6.3)	2.91 (7.5)	3.36 (10.4)	1.42 (24.2)	1.69 (1.8)	1.56 (1.5)	1.67 (1.8)	2.47 (5.1)
T_3D_1	4.73 (51.4)	4.80 (22.01)	6.14 (36.7)	1.91 (80.2)	5.44 (28.6)	5.91 (34.0)	6.65 (43.2)	2.03 (105.8)	3.27 (9.7)	3.69 (12.6)	3.95 (14.6)	6.15 (36.9)
T_3D_2	2.96 (7.7)	3.15 (8.9)	3.93 (14.4)	1.52 (31.1)	3.70 (12.7)	3.88 (14.1)	4.25 (17.1)	1.66 (43.8)	2.22 (3.9)	2.36 (4.6)	2.59 (5.7)	3.90 (14.2)
T_3D_3	2.81 (6.9)	3.03 (8.2)	3.76 (13.1)	1.48 (28.3)	3.96 (14.7)	3.74 (13.0)	4.07 (15.5)	1.65 (43.2)	2.37 (4.6)	2.26 (4.1)	2.49 (5.2)	3.87 (13.9)
LSD (p=0.05)	0.10	0.11	0.14	0.03	0.12	0.13	0.15	0.04	0.08	0.08	0.08	0.17

T_1: Conventional tillage - Sowing, T_2: Minimum tillage - Sowing, T_3: Zero tillage-Transplanting, N_1: 100% recommended NPK (50:40:25 kg NPK/ha), N_2:100% recommended NPK + 7.5 t FYM/ha N_3:Horsegram residue mulch + 100% recommended NPK, N_4:Horsegram residue mulch + 50% recommended NPK + 25% N through FYM + *Azotobacter* seed treatment, N_5: Horsegram residue mulch + Fertilizers based on soil test results, D_1 - 0-10 cm, D_2 - 10-20 cm, D_3 - 20-30 cm. BLW-Broad leaved weeds, * - sqrt(x+1) transformation, # - log(x+2) transformation, Figures in parentheses indicate original values, LSD-Least Significant difference, NS-Non significant.

1.63 to 2.62/kg soil at 30 days and 0.02 to 0.70/kg soil at 60 days) during 2014.

The similar trend of soil weed seed bank **(Table 6)** at 15, 30 and 60 days were also observed during 2015. Lower weed seed number in conventional tillage was attributed to soil pulverization, removal of emerged weeds by follow up inter cultivation at 25 and 50 DAS which helped to lower the soil seed bank by avoiding further development and flowering of weeds. Nichols *et al.* (2015) stated that tillage is a mechanical method of weed control that can kill live weeds before they reproduce, thus preventing seed production and it is a useful tool for controlling established weed populations, curtailing the weed seed bank and weed intensities. Significantly higher soil weed seed bank under zero tillage was a result of addition and deposition of more number of weed seeds in the top soil layer due to no soil inversion, soil disturbance, no management actions on weeds after their emergence in the cropping season and increased deposition of weed seeds as a result of flowering of weeds from previous seasons. These weed seeds will germinate and emerge in the next season and so the cycle continues with an increase in soil weed seed

Table 6. Weed no./kg of soil at different days as influenced by tillage and nutrient management practices during 2015

Treatment	At 15 days				At 30 days				At 60 days			
	Sedge*	Grasses*	BLW*	Total#	Sedge*	Grasses*	BLW*	Total#	Sedge*	Grasses*	BLW*	Total*
Tillage practices (T)												
T_1	1.78 (2.4)	2.03 (3.4)	2.47 (5.5)	1.05 (11.3)	2.21 (4.1)	2.40 (5.1)	2.97 (8.4)	1.23 (17.6)	1.37 (1.0)	1.51 (1.4)	1.57 (1.6)	2.08 (4.1)
T_2	2.59 (6.1)	3.08 (8.9)	4.06 (16.4)	1.47 (31.5)	3.23 (9.7)	3.78 (14.1)	4.50 (20.4)	1.62 (44.2)	2.00 (3.1)	2.08 (3.5)	2.18 (4.0)	3.32 (10.7)
T_3	3.64 (13.1)	3.98 (15.6)	4.88 (24.1)	1.69 (52.8)	4.39 (18.8)	4.74 (22.5)	5.24 (27.9)	1.81 (69.3)	2.64 (6.2)	2.79 (7.2)	3.03 (8.6)	4.67 (22.0)
LSD (p=0.05)	0.05	0.06	0.08	0.02	0.07	0.09	0.09	0.02	0.04	0.12	0.04	0.09
Nutrient management practices (N)												
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Depths (C)												
D_1	3.51 (12.6)	3.86 (15.2)	4.92 (25.4)	1.66 (53.1)	3.98 (16.3)	4.65 (22.5)	5.48 (31.0)	1.78 (69.8)	2.43 (5.4)	2.75 (7.2)	2.88 (8.0)	4.42 (20.6)
D_2	2.52 (5.6)	2.92 (7.7)	3.63 (12.5)	1.42 (25.8)	3.12 (9.0)	3.48 (11.5)	4.06 (15.7)	1.56 (36.2)	1.91 (2.7)	2.03 (3.2)	2.18 (3.9)	3.24 (9.9)
D_3	1.98 (3.5)	2.31 (5.0)	2.85 (8.2)	1.13 (16.6)	2.74 (7.5)	2.78 (7.7)	3.16 (10.0)	1.32 (25.2)	1.67 (2.1)	1.59 (1.8)	1.72 (2.3)	2.41 (6.1)
LSD (p=0.05)	0.05	0.06	0.08	0.02	0.07	0.09	0.09	0.02	0.04	0.12	0.04	0.09
Tillage (T) × Nutrient management practices (N)												
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Tillage (T) × Depths (C)												
T_1D_1	2.20 (3.8)	2.43 (4.9)	3.00 (8.0)	1.27 (16.7)	2.53 (5.4)	2.86 (7.2)	3.61 (12.0)	1.43 (24.6)	1.57 (1.5)	1.84 (2.4)	1.87 (2.5)	2.71 (6.3)
T_1D_2	2.04 (3.2)	2.37 (4.6)	2.85 (7.1)	1.23 (14.9)	2.55 (5.5)	2.79 (6.8)	3.42 (10.7)	1.40 (23.0)	1.58 (1.5)	1.74 (2.0)	1.83 (2.3)	2.62 (6.0)
T_1D_3	1.11 (0.2)	1.30 (0.7)	1.55 (1.4)	0.64 (2.3)	1.55 (1.4)	1.53 (1.4)	1.87 (2.5)	0.86 (5.3)	1.26 (0.6)	1.30 (0.7)	1.64 (1.7)	2.00 (3.0)
T_2D_1	3.41 (10.6)	3.93 (14.5)	5.27 (26.9)	1.73 (52.0)	3.93 (14.4)	4.88 (22.8)	5.85 (33.3)	1.86 (70.5)	2.43 (4.9)	2.70 (6.3)	2.79 (6.8)	4.36 (18.0)
T_2D_2	2.45 (5.1)	2.97 (7.8)	3.88 (14.1)	1.46 (27.0)	3.08 (8.6)	3.57 (12.1)	4.30 (17.5)	1.60 (38.3)	1.91 (2.7)	1.99 (2.9)	2.11 (3.5)	3.17 (9.1)
T_2D_3	1.90 (2.6)	2.33 (4.5)	3.02 (8.2)	1.23 (15.3)	2.67 (6.2)	2.88 (7.3)	3.35 (10.4)	1.41 (23.8)	1.66 (1.7)	1.55 (1.4)	1.65 (1.7)	2.42 (4.9)
T_3D_1	4.92 (23.2)	5.21 (26.2)	6.50 (41.2)	1.97 (90.6)	5.47 (28.9)	6.21 (37.6)	6.98 (47.7)	2.07 (114.2)	3.29 (9.8)	3.71 (12.8)	3.97 (14.7)	6.20 (37.4)
T_3D_2	3.08 (8.5)	3.42 (10.7)	4.16 (16.3)	1.57 (35.4)	3.72 (12.8)	4.08 (15.6)	4.46 (18.9)	1.69 (47.3)	2.24 (4.0)	2.38 (4.6)	2.61 (5.8)	3.93 (14.4)
T_3D_3	2.93 (7.6)	3.29 (9.8)	3.98 (14.8)	1.53 (32.2)	3.98 (14.8)	3.92 (14.4)	4.27 (17.2)	1.69 (46.4)	2.39 (4.7)	2.27 (4.2)	2.51 (5.3)	3.90 (14.2)
LSD (p=0.05)	0.09	0.11	0.14	0.03	0.12	0.16	0.15	0.03	0.07	0.22	0.07	0.16

T_1: Conventional tillage - Sowing, T_2: Minimum tillage - Sowing, T_3: Zero tillage-Transplanting, N_1: 100% recommended NPK (50:40:25 kg NPK/ha), N_2: 100% recommended NPK + 7.5 t FYM/ha, N_3:Horsegram residue mulch + 100% recommended NPK, N_4: Horsegram residue mulch + 50% recommended NPK + 25 % N through FYM + *Azotobacter* seed treatment, N_5:Horsegram residue mulch + Fertilizers based on soil test results, D_1 - 0-10 cm, D_2 - 10-20 cm, D_3 - 20-30 cm. BLW-Broad leaved weeds, *- sqrt(x+1) transformation, # - log(x+2) transformation, Figures in parentheses indicate original values, LSD-Least Significant difference, NS-Non significant bank. Zero tillage resulted in the deposition of more seeds and propagules of predominant annual and perennial weeds near the soil surface (Subbulakshmi *et al*. 2009). Among different soil depths, 0-10 cm has a higher number of weed seeds as a result of soil inversion which brings the soil from the lower layer to the top layer, no soil disturbance under zero tillage and deposition of more number of weed seeds in the top layer and the lowest weed seeds at 20-30 cm soil layer was due to slower movement of these weed seeds to the lower layer. Among tillage and depth interactions, significantly higher weed seeds were observed on zero tillage and 0-10 cm interaction, due to no soil disturbance in zero tillage that too on top 0-10 cm soil surface layer have together responsible for higher weed seed bank at the top undisturbed layer. Whereas, lowest weed seed number in conventional tillage in 20-30 cm soil depth samples was because of intensive frequent tillage which has shifted lower soil depth weed seeds to the top layer and left the lower layer with fewer weed seeds. These outcomes are supported by Barberi *et al*. (2001) who quoted that vertical distribution of seeds will dictate which seeds produce potentially crop-competitive weeds.

The conventional tillage ((2 ploughings + 1 harrowing + 2 inter cultivation at 25 and 50 days after sowing (DAS)) was found better for effective management of weeds in finger millet crop on *Alfisols* due to reduced weed growth due to reduced soil weed seed bank with the improved grain and straw yield over the minimum and zero tillage practices. Whereas, the nutrient management practices have not significantly varied in the control of weeds. The application of 100% recommended NPK + 7.5 t FYM/ha has resulted in significantly higher grain and straw yields over other nutrient management practices.

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Variations in morpho-physiological traits of sweet corn in response to weed management

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ABSTRACT

A field experiment was conducted in spring 2016 and 2017 at G.B.P.U.A&T, Pantnagar to evaluate the effect of different weed management practices on the morphological and physiological parameters of sweet corn (*Zea mays* L. var. '*Sugar 75*'), which determines the yield directly or indirectly. The experiment was comprised of twelve treatments. Effect of weed management practices were studied over several growth characters *viz.* plant height, crop dry matter accumulation, leaf area index, Fv/Fm value, crop growth rate, leaf chlorophyll content, yield, harvest index and nutrient uptake by crop. At 45 DAS, maximum crop height (57.5 cm), crop dry matter (776.5 g/m^2), CGR (26.1 g/m^2/day), LAI (6.71) and SPAD (60.4) records were obtained from twice hand weeding at 20 and 40 DAS. Fv/Fm value remained unaffected by weed interferences. A significant positive correlation of weed control efficiency was found with all the growth parameters However, weed dry matter accumulation and weed density impacted morpho-physiological characters and ultimate yield in a negative way.

INTRODUCTION

Maize is known as the "Queen of Cereals" due to its omnipresence and versatility in usage. Sweet corn (*Zea mays* L. var. '*Sugar 75*') is a special kind of maize having more than 16% sugar in its kernel. It is mainly grown for fresh consumption purpose and may also be used in industrially processed products. Its taste and nutritional value have made it a valued crop of eminence in all over the world and the scope of corn production is constantly increasing (Olabode and Sangodele 2015). Among the several factors, most critical factor for limiting the yield of maize appears to be the weeds, competing with the crop for nutrients, water, sunlight and space. Maize is highly suffered by the weeds due to wider spacing and slow initial growth, which favour the growth of weeds. Yield losses due to weeds are evident to the extent of 28 to 93%, depending on the type of weed flora, intensity and duration of crop-weed competition (Sharma and Thakur 1998).

Use of herbicides for managing the weeds is not necessarily an economically and ecologically fitting option every time as there are limitations and advantages of every weed control method, therefore integrated weed management is a good option for a sustainable production system (Ehsas *et al.* 2016). In the current study, the effect of different weed control measures on the morpho-physiological determinants of yield was studied. The morphological and physiological traits for yield variations were identified and the effect of weed management on them and how the final yield benefit is derived were investigated.

MATERIALS AND METHODS

The present experiment was conducted during spring season of 2016 and 2017 in N.E.B.C.R.C. of G.B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand), India (29 ^{0}N, 79.3 ^{0}E, 243.83 m) with average annual rainfall of 1350 mm. Soil of the experimental site was sandy loam, neutral in pH with high organic carbon (0.79%), medium available nitrogen (314.3 kg/ha), phosphorus (19.8 kg/ha) and potassium (220.3 kg/ha). Sweet corn variety '*Sugar 75*' was grown. The experiment was laid out in a randomized complete block design with twelve different weed management treatments *viz.* intercropping with mung bean, paddy straw mulching at 5 t/ha, atrazine at 1000 g/ha, halosulfuron-methyl at 90 g/ha, tembotrione at 120 g/ha, atrazine at 1000 g/ha with paddy straw mulching, atrazine at 1000 g/ha *fb* halosulfuron-methyl at 90 g/ha, atrazine at 1000 g/ha *fb* tembotrione at 120 g/ha, atrazine at 1000 g/ha *fb* one hand weeding at 40 DAS, twice hand weeding at 20 and 40 DAS, weed free and weedy check, replicated thrice. Observations on morphological features were taken in field condition while analytical and physiological parameters were evaluated under lab conditions. Morpho-physiological observations include plant height, crop dry matter accumulation, leaf area index, Fv/Fm value (Chlorofluorometer), crop growth rate, leaf chlorophyll content index (SPAD), yield, harvest index and nutrient uptake by crop. Observations on weeds include total weed dry matter accumulation, total weed density and weed control efficiency at 45 DAS.

Data from both the years were pooled for analysis as no significant time to treatment interaction was found (Elsami and Afgani 2009). The weed density and dry matter were transformed using square root transformation ($\sqrt{(x+1)}$) for the purpose of treatment comparison using ANOVA. Effect of the treatments was compared statistically by Fisher's least significant difference method at 5% level of significance (Gomez and Gomez 1984). All statistical analysis were made using IBM SPSS 24.0 software package developed by IBM Corp. (2016).

RESULTS AND DISCUSSION

Weed studies

The major weed species which infested the experimental plots were *Cynodon dactylon* (10.4%), *Echinochloa colona* (4.6%) among grasses, *Alternanthera sessilis* (11.6%), *Celosia argentea* (7.5%) among broad-leaf weeds and *Cyperus rotundus* (57.8%) among sedges at 45 DAS. Weedy plots were recorded with highest total weed dry matter at all the crop growth stages. The effect of different treatments on total weed dry matter accumulation was found significant. The lowest total weed dry matter accumulation was recorded from twice hand weeded plots followed by pre-emergence application of atrazine 1000 g/ha *fb* post-emergence application of tembotrione 120 g/ha (**Table 1**). Swetha *et al.* (2015) has also reported similar findings. Efficient control of grassy and non-grassy weeds in maize with post-emergence application of tembotrione has been also reported by Singh *et al.* (2012).

All the weed control treatments reduced the weed density significantly over the weedy check. The lowest weed density was recorded from the twice hand weeded plots up to 45 DAS of the crop and afterwards the lowest total weed density was recorded with pre-emergence application of atrazine 1000 g/ha *fb* post-emergence application of halosulfuron methyl 90 g/ha due to effective control of *Cyperus rotundus* which had contributed about 70% of the total weed population at later stages of crop growth (**Table 1**). Similar results were also established in controlling *Cyperus rotundus* effectively in turf grass with halosulfuron-methyl by Desai *et al.* (2017).

At 45 DAS, the highest weed control efficiency was recorded from the twice hand weeded plots at 20 and 40 DAS which was at par with the pre-emergence application of atrazine 1000 g/ha *fb* post-emergence application of tembotrione 120 g/ha among the weed control treatments (**Table 1**). Better performance of pre-emergence application of atrazine 1000 g/ha *fb* post-emergence application of tembotrione 120 g/ha, may be attributed to good initial control over grassy and broadleaf weeds through pre-emergence application of atrazine 1000 g/ha and the weeds were further taken care by the post-emergence application of tembotrione 120 g/ha at 20 DAS.

Table 1. Effect of weed management practices on weed density, weed dry matter accumulation and weed control efficiency at 45 DAS (pooled data)

Treatment	Weed density (no./m^2)	Weed dry matter accumulation (g/m^2)	Weed control efficiency at (%)
Intercropping with mung bean	13.0 (168.0)	10.3 (105.4)	23.7
Paddy straw mulching 5 t/ha	11.0 (119.3)	8.5 (71.7)	48.0
Atrazine (1000 g/ha)	10.2 (102.7)	7.6 (57.1)	58.7
Halosulfuron-methyl (90 g/ha)	8.1 (65.3)	8.4 (69.2)	49.9
Tembotrione (120 g/ha)	7.8 (60.0)	4.8 (22.4)	83.8
Atrazine + paddy straw mulching (1000 g/ha + 5 t/ha)	9.9 (97.3)	7.2 (50.3)	63.6
Atrazine *fb* halosulfuron-methyl (1000g/ha *fb* 90)	5.9 (33.3)	6.6 (43.0)	68.9
Atrazine *fb* tembotrione (1000 g/ha *fb* 120)	7.0 (48.0)	3.8 (13.4)	90.3
Atrazine *fb* 1 hand weeding at 40 DAS (1000 g/ha)	7.1 (49.3)	4.8 (22.4)	83.7
Two hand weeding's at 20 and 40 DAS	4.3 (17.3)	3.4 (10.4)	92.4
Weed free	1.0 (0.0)	1.0 (0.0)	100.0
Weedy check	15.2 (230.7)	11.8 (138.1)	-
LSD (p=0.05)	0.68	0.14	3.96

*Original values are given in parentheses

Crop studies

The fastest increment in plant height was observed between the knee-high stage and 50% tasseling stage or in the grand growth phase to the tune of 8.63 cm/day in weed-free plots. All the treatments, except intercropping with mung bean, resulted in significantly higher plant height than weedy check. Among the weed control treatments, twice hand weeding at 20 and 40 DAS was found to have maximum plant height which was at par with pre-emergence application of atrazine 1000 g/ha *fb* post-emergence application of tembotrione at 120 g/ha which was as good as weed-free plots, may be due to the efficient weed control of the treatments as evidenced by the higher weed control efficiency and lower weed dry matter accumulation. Effect of weed interference on plant height of maize was also reported by Da Silva *et al.* (2005).

Crop dry matter accumulation is one of the best indicators for predicting the crop yield because the accumulation of dry matter is directly related to effective photosynthesis which is the pre-requisite for obtaining higher yield levels. Among the weed control treatments, twice hand weeding at 20 and 40 DAS was recorded to have maximum crop dry matter accumulation over all the crop stages which was at par with pre-emergence application of atrazine at 1000 g/ha *fb* post-emergence application of tembotrione at 120 g/ha and comparable to weed free plots, may be due to effective weed control which had caused less competition to the crop.

Similar trend was found in Crop growth rate (CGR). The highest CGR at 45 DAS was recorded from twice hand weeding at 20 and 40 DAS (26.10 g/ m^2/day) which was at par with pre-emergence application of atrazine at 1000 g/ha *fb* post-emergence application of tembotrione 120 g/ha, alone application of tembotrione 120 g/ha and comparable to that of weed free plots (**Table 2**).

At 45 DAS maximum LAI, SPAD readings were also recorded from twice hand weeding at 20 and 40 DAS (6.71, 60.4) which was at par with pre-emergence application of atrazine at 1000 g/ha *fb* post-emergence application of tembotrione 120 g/ha, alone application of tembotrione 120 g/ha and weed free plots (**Table 2**). The effect of weed control on CGR, LAI was also reported by Teymoori *et al.* (2013). However, Fv/Fm value, the indicator of the PS-II activity and photosynthetic efficiency (Murchie and Lawson 2013), was found to remain unaffected by weed interference.

The highest green cob yield was recorded with twice hand weeding at 20 and 40 DAS (15.46 t/ha) which was at par with pre-emergence application of atrazine 1000 g/ha *fb* post-emergence application of tembotrione 120 g/ha (15.31 t/ha) among the weed control treatments. Pre-emergence application of atrazine 1000 g/ha *fb* post-emergence application of tembotrione 120 g/ha has resulted in highest harvest index (0.34) which was at par with alone post-emergence application of tembotrione 120 g/ha (0.32), pre-emergence application of atrazine 1000 g/

Table 2. Effect of weed management practices on morpho-physiological attributes of sweet corn at 45 DAS and yield (pooled data)

Treatment	Plant height (cm)	Crop dry matter accumulation (g/m^2)	LAI	Fv/Fm	Crop growth rate (g/m^2/day)	SPAD (CCI)	Cob yield (t/ha)	Harvest index (%)	Nitrogen uptake (kg/ha)	Phosphorus uptake (kg/ha)	Potassium uptake (kg/ha)	B:C ratio
Intercropping with mung bean	23.3	278.4	4.07	0.804	9.52	32.6	5.33	0.26	160.7	36.2	118.9	1.11
Paddy straw mulching 5 t/ha	28.1	412.0	3.86	0.809	11.16	31.4	6.88	0.30	178.5	40.4	125.6	1.37
Atrazine (1000 g/ha)	33.1	492.2	4.40	0.846	12.31	31.4	8.81	0.31	215.1	48.7	143.3	1.80
Halosulfuron-methyl (90 g/ha)	28.2	433.3	3.83	0.799	11.82	30.8	6.96	0.30	177.0	40.1	117.8	1.34
Tembotrione (120 g/ha)	47.8	700.3	5.93	0.842	22.21	54.7	13.36	0.32	307.0	69.6	196.6	2.59
Atrazine + paddy straw mulching (1000 g/ha + 5 t/ha)	38.0	516.8	5.06	0.797	14.67	46.8	9.21	0.28	251.3	56.7	180.4	1.78
Atrazine *fb* halosulfuron-methyl (1000g/ha *fb* 90)	42.8	601.4	4.96	0.816	17.81	49.0	10.81	0.31	272.7	61.7	191.5	2.02
Atrazine *fb* tembotrione (1000 g/ha *fb* 120)	56.7	766.9	6.12	0.875	24.53	59.2	15.31	0.34	343.2	77.9	216.3	2.87
Atrazine *fb* 1 hand weeding at 40 DAS (1000 g/ha)	46.3	691.9	5.51	0.842	20.78	52.7	13.13	0.32	312.9	70.8	211.5	2.49
Two hand weeding's at 20 and 40 DAS	57.5	776.5	6.71	0.836	26.10	60.4	15.46	0.31	369.2	83.7	233.7	2.75
Weed free	59.3	789.9	6.66	0.872	26.36	61.8	15.92	0.32	378.2	85.5	240.2	2.55
Weedy check	23.3	253.6	3.69	0.781	8.54	29.9	5.13	0.27	149.8	33.7	110.7	1.08
LSD (p=0.05)	3.45	39.6	1.19	NS	5.85	6.6	1.42	0.03	44.4	8.5	68.7	-

ha *fb* one hand weeding at 40 DAS (0.32) and twice hand weeding at 20 and 40 DAS (0.31) (**Table 2**).

The maximum nitrogen (369.2 kg/ha), phosphorus (83.7 kg/ha) and potassium (233.7 kg/ha) uptake by the crop were recorded in twice hand weeding at 20 and 40 DAS which was at par with pre-emergence application of atrazine at 1000 g/ha *fb* post-emergence application of tembotrione at 120 g/ha among the weed control treatments owing to lesser competition faced by crop from weeds due to superior control over weeds.

Growth characters of sweet corn which are the direct or indirect determinants of yield are significantly affected by the weed management practices. Especially, the treatments having higher weed control efficiency are found to have higher plant height, crop dry matter, crop growth rate, LAI and final yield. Twice hand weeding and pre-emergence application of atrazine 1000 g/ha *fb* post-emergence application of tembotrione 120 g/ha were found best among the weed control treatments with respect to all growth parameters due to higher weed control efficiency, lower weed density and lower weed dry matter accumulation. Better understanding of these morphological and physiological characters may help in the selection of better agrotypes and weed management practices for achieving a higher productivity.

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Weed management in blackgram

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ABSTRACT

A replicated field experiment was conducted during 2016 and 2017 for selecting suitable herbicide for weed management in rainfed blackgram at Krishi Vigyan Kendra Farm, Ashokenagar, West Bengal, India. Among the herbicides tested, pre-emergence application (PE) of pendimethalin 1.0 kg/ha *fb* post-emergence application (PoE) quizalofop-ethyl 50 g/ha 25 days after seeding (DAS) resulted in lower weed density and higher weed control efficiency (92.10%) with an average seed yield of 0.82 t/ha, which was 48.35% grain yield over the control. Pendimethalin (PE) 1.0 kg/ha *fb* quizalofop-ethyl 50 g/ha (PoE) could be used for effective and economic weed control in blackgram in rainfed conditions.

INTRODUCTION

Blackgram (*Vigna mungo* L.) is an important legume crop cultivated worldwide in tropical and subtropical regions of the world and is valued for high protein in its seeds. India is the world's largest producer as well as consumer of blackgram with 1.5 to 1.9 million tons of blackgram produced annually from about 3.5 million hectares of area, with an average productivity of 555 kg/ha (Anonymous 2014). In West Bengal, black gram is grown on about 76,000 hectares (Anonymous 2015) area, mostly under rainfed conditions. The major problem in blackgram production, particularly in *Kharif* season, is infestation of weeds. Associated weeds compete for nutrients, moisture, light and space. Due to non-availability and high prices of labour and continuous rains, it becomes difficult to manually remove weeds during critical period of crop growth, which is critical for higher crop productivity (Adhikary 2016). Unchecked weeds were reported to cause a considerable reduction in blackgram seed yield (upto 46-53%) in summer (Bhandari *et al*. 2004) and *Kharif* season (43.2-64.1 %) (Rathi *et al.* 2004). The losses caused by weeds exceed the losses from any other category of agricultural pests in West Bengal. Therefore, under these circumstances, use of herbicides may be desirable for the control of weeds particularly at early stages, which will control the emerging weeds for a substantial period of time. Farmers do not follow chemical weed control in blackgram, except for a few farmers who use pre-emergence herbicides followed by one or two hand weeding. Singh *et al*. (2014) pointed out the need of post-emergence herbicide to control the second flush of weeds in pulses and to reduce human labour. The post-emergence herbicides such as quizalofop-ethyl 50 to 75 g/ha were shown to provide season-long control of many weeds without crop injury (Ram *et al*. 2013). Imazethapyr 25 g/ha was found effective in controlling weeds on rainfed blackgram (Nandan *et al*. 2011).

Since application of single herbicide may not be effective in providing broad spectrum weed control, application of pre- and post-emergence herbicides in sequence or integrated with manual weeding may be more beneficial (Balyan *et al*. 2016). Hence, the present study was undertaken to evaluate the various post-emergence herbicides along with one pre-emergence and hand weeding for managing weeds during critical period of crop weed competition in blackgram under rainfed conditions.

MATERIALS AND METHODS

The experiment was conducted during two consecutive *Kharif* seasons of 2016 and 2017 at the Krishi Vigyan Kendra Farm, Ashokenagar (latitude: 22° 50' 9.6324'' N, longitude: 88° 38' 13.8192'' E and altitude: 10.47 m) West Bengal, India. This soil was medium in organic carbon content (0.67%) and the available nutrient status was low in nitrogen, medium range of phosphorus and the potassium status was high with neutral to alkaline in soil reaction. The variety used was '*Sulata*'. The experiment was laid out in randomized block design with seven treatments, *viz*. pre-emergence application (PE) of pendimethalin 1.0 kg/ha (PE) *fb* interculture 25 days after seeding (DAS); interculture 15 DAS *fb* post-emergence application (PoE) of imazethapyr 100 g/ha at 25 DAS; interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha at 25 DAS; pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha at 25 DAS; pendimethalin1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 25 DAS; weed-free and weedy check. The test herbicides were sprayed with the spray volume of 500 liters/ha using knapsack sprayer with flood jet deflector WFN 040 nozzle. All the other recommended agronomic and plant protection measures were adopted to raise the crop and the intercultural practices were taken as need based. The data on weed density and biomass were recorded at 45 DAS and weed control efficiency (WCE) of different treatments was computed using data on weed biomass. The data were analyzed following analysis of variance (ANOVA) technique and mean differences were adjusted by the multiple comparison test (Gomez and Gomez 1984)

RESULTS AND DISCUSSION

Effect on weeds

The major weeds at the experimental site were: *Cynodondactylon, Dactyloctenium aegyptium, Digitaria sanguinalis, Panicum maximum, Eleusine indica, Cyperus rotundus, Commelina bengalensis, Ageratum conyzoides, Euphorbia hirta, Tribulus terrestris, Trianthema monogynya, Fimbristylis penera, Digera arvensis, Cleome viscosa, Celosia argentia etc*. Similar observations were made by Balyan *et al.* (2016).

The highest weed density (108.33 /m^2) and weed biomass (80.22 g /m^2) at 45 DAS were recorded in weedy check (**Table 1**). Among herbicide treatments, pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha at 25 DAS was significantly superior in reducing weed density (11.67/m^2) at 45 DAS followed by pendimethalin 1.0 kg/ha (PE) *fb* interculture 25 DAS, pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha at 25 DAS and remained statistically superior over all other weed management practices except weed free treatment.

Weed biomass was reduced significantly (6.34 g/m^2) at 45 DAS with pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha at 25 DAS. About 86% weed biomass reduction was observed with application of pendimethalin1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ ha 30 DAS as also reported by Balyan *et al.* (2016).

The highest weed control efficiency (96.66 %) at 45 DAS (**Table 1**) was recorded in weed free. and in pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha at 25 DAS (92.10 %). Other herbicides, pendimethalin, imazethapyr, quizalofop-ethyl alone or in combination also registered notable weed control efficiency (78.06 to 88.01%).

Weed persistence index (WPI) and herbicide efficacy indices (HEI) express the tolerance of weeds to different herbicide treatments as well as their efficacy to eradicate the weeds (**Table 2**). Pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 25 DAS recorded lowest WPI (0.73%) followed by pendimethalin 1.0 kg/ha (PE) *fb* interculture 25 DAS. Pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 25 DAS produced higher HEI (11.85%) than all other herbicidal treatments. Maximum crop resistance index (CRI), 58.31 was noticed in weed free plots. Balyan *et al.* (2016) also observed similarly in blackgram. HEI, WPI, CRI and WI were earlier reported by Adhikary *et al.* (2016) in groundnut.

Effect on crop

Germination was not affected by herbicide application (**Table 3**) and around 93.50% to 97.23% seed germination was occurred. Herbicidal effect on nodulation in blackgram crop was very prominent.

Table1. Effect of different weed control treatments on weed density and biomass at 45 DAS of blackgram (pooled value)

Treatment	Weed density (no./m^2) 45 DAS	Weed biomass (g/m^2) 45 DAS	Weed control efficiency (%) 45 DAS	Weed infestation (%)
Pendimethalin 1.0 kg/ha (PE) *fb* interculture 25 DAS	16.67	9.62	88.01	23.26
Interculture 15 DAS *fb* imazethapyr 100 g/ha 25 DAS	22.33	17.6	78.06	28.88
Interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha 25 DAS	20.67	15.58	80.58	27.31
Pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 25 DAS	14.33	10.78	86.56	20.67
Pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 25 DAS	11.67	6.34	92.10	17.50
Weed-free	6.67	2.68	96.66	10.81
Weedy check	108.33	80.22	0	66.33
LSD (p=0.05)	5.98	3.24	-	-

The number of root nodules differed from treatment to treatment (21.00 to 25.33).The maximum number of nodules per plant (25.33) was recorded in weed free plots. Pre-emergence application of pendimethalin 1.0 kg/ha with quizalofop-ethyl 50 g/ha at 25 DAS recorded 24.00 nodules per plant. While the lowest nodules were found in weedy check plots. Similar results were reported by Adhikary *et al.* (2016).

Significant difference in plant height were observed with pre-emergence and post-emergence herbicides applied alone or in combination ($p<0.05$). The pre-emergence application of pendimethalin1.0 kg/ha (PE) recorded 62.25 cm plant height Among the post-emergence treatments, the maximum height (61.67 cm) was recorded under quizalofop-ethyl 50 g/ha at 25 DAS treatment (**Table 3**). The combined application of pendimethalin 1.0 kg/ha PE and quizalofop-ethyl 50 g/ha PoE at 25 DAS recorded 63.39 cm plant height, which was highest among the herbicidal treatments. The lowest plant height was observed in the weedy check plots (56.30 cm). The tested herbicides had no significant difference on days to 50% bloom. 50% blooming has occurred between 48 to 52 days. Similar trend was found by Balyan *et al.* (2016).

The longest pod size 5.63 cm was recorded in weed free plots and the shortest (5.27 cm) was found in weedy check plots (**Table 4**). 5.50 cm long pod was found in pendimethalin 1.0 kg/ha and quizalofop-ethyl 50 g/ha treated plots.

Number of pods per plant was significantly influenced by weed control practices (**Table 4**). Significantly higher number of pods (17.55) were produced by application of pendimethalin1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha at 25 DAS. However pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 25 DAS was on par with treatment T5. The highest number of pods per plant (19.24) was found in weed free plots and significantly lowest number of pods per plant was recorded by weedy check (14.5). The higher number of seeds per pod was observed in (T6) weed free plots (8.86) and was followed by (T5) pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha at 25 DAS (8.69). While, the least numbers of seeds per pod were observed in weedy check (6.56). Significantly higher test weight was recorded in weed free (4.98 g) which was on par with pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha at 25 DAS (4.66 g). Significantly lowest test weight was recorded in weedy check (3.67 g). Similar result was recorded by Balyan *et al.* (2016).

Higher seed yield (0.82 t/ha) was recorded with the application of pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 25 DAS, which showed 48.35% increment over the weedy check (**Table 4**).

Table 2. Effect of treatments on weed indices in blackgram (pooled value)

Treatment	HEI	WPI	CRI	WI	AMI
Pendimethalin 1.0 kg/ha (PE) *fb* interculture 25 DAS	6.62	0.78	14.96	7.89	-0.50
Interculture 15 DAS *fb* imazethapyr 100 g/ha 25 DAS	3.37	1.06	7.93	10.68	-0.46
Interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha 25 DAS	3.91	1.02	9.06	9.71	-0.46
Pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 25 DAS	6.42	1.02	13.86	4.37	-0.46
Pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 25 DAS	11.85	0.73	24.50	0.61	-0.48
Weed-free	28.38	0.54	58.31	0.00	-0.50
Weedy check	0.00	1.00	1.00	48.67	

HEI = Herbicide efficacy index; WPI= Weed persistence index; CRI = Crop resistance index; WI = Weed Index; AMI = Agronomic management index

Table 3. Effect of different weed control treatments on growth parameters of blackgram (pooled value)

Treatment	Germination (%)	Plant height (cm)	Nodules/ plant	Days to 50% bloom
Pendimethalin 1.0 kg/ha (PE) *fb* interculture 25 DAS	94.67	62.25	23.67	48.33
Interculture 15 DAS *fb* imazethapyr 100 g/ha25 DAS	95.33	59.59	22.67	51.67
Interculture 15 DAS *fb* quizalofop-ethyl 50g/ha 25 DAS	94.23	61.67	21.67	50.67
Pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr100 g/ha 25 DAS	93.50	60.59	22.00	49.67
Pendimethalin 1.0 kg/ha (PE) *fb* quizalofopethyl50 g/ha 25 DAS	97.23	63.39	24.00	51.33
Weed-free	97.00	65.42	25.33	50.33
Weedy check	96.5	56.30	21.00	49.67
LSD (P=0.05)	-	2.65	3.14	-

Table 4. Effect of different weed control treatments on yield attributing characters, yield and economics of blackgram (pooled value)

Treatment	Pod size (cm)	Pods/ plant	Seeds / pod	100-seed weight (g)	Yield (t/ha)	Yield increase (%)	Gross cost ($x10^3$ `/ha)	Gross return ($x10^3$ `/ha)	B:C ratio
Pendimethalin 1.0 kg/ha (PE) *fb* interculture 25 DAS	5.47	16.40	7.87	4.59	0.76	44.27	24.75	41.74	1.69
Interculture 15 DAS *fb* imazethapyr 100 g/ha 25 DAS	5.43	15.98	7.38	4.28	0.74	42.53	24.60	40.48	1.65
Interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha 25 DAS	5.33	16.33	7.55	4.39	0.74	43.15	24.65	40.92	1.66
Pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 25 DAS	5.20	17.45	8.05	4.43	0.79	46.32	24.85	43.34	1.74
Pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 25 DAS	5.50	17.55	8.69	4.66	0.82	48.35	24.54	45.04	1.84
Weed-free	5.63	19.24	8.86	4.98	0.82	48.67	25.50	45.32	1.78
Weedy check	5.27	14.50	6.56	3.67	0.42	0.00	21.50	23.26	1.08
LSD (p=0.05)	1.37	2.01	1.28	NS	0.13	-	-	-	-

The highest per cent (48.67%) increase in seed yield of blackgram with the weed free over the weedy check. The seed yield was negatively associated with total weed density, weeds biomass and positively associated with plants (no./m^2), pods/plant, seed/pod and 100-seed weight (g). This might be due to effective control of weeds, less crop weed competition throughout the crop growth period which resulted in improved growth parameters of the crop. These findings were agreement with Singh *et al*. (2014); Rajput and Kushwah (2004). The highest value of gross return (45320) and B:C ratio (1.78) was recorded in weed free while highest B:C ratio (1.84) was recorded with pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha at 25 DAS.

Application of pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha at 25 DAS could be the possible alternative options for effective and economic weed management in blackgram under rainfed system in West Bengal conditions.

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Weed management effect on growth and yield of sugarcane

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ABSTRACT

An experiment was conducted at Agricultural Research Station, Dhadesugur, UAS, Raichur, Karnataka during 2015-16 and 2016-17 to study the effect of weed control practices on growth and yield of sugarcane and its associated weeds. Dominant weeds were *Echinochloa* spp. *(E. crus-galli* and *E. colona), Dactyloctenium aegyptium, Eleusine indica, Brachiaria spp. (B. mutica* and *B. ramosa)* and *Digitaria sanguinalis* among grasses, *Eclipta alba, Chenopodium album, Physalis minima, Ageratum conyzoides, Parthenium hysterophorus* and *Portulaca oleracea* as broad-leaf weeds and *Cyperus* spp. *(C. rotundus* and *C. iria)* as sedges. Among the herbicidal treatments, pyrazosulfuron-ethy + metribuzin + 2,4-D sodium salt WDG (3000 g/ha) recorded significantly higher millable cane yield (119.5 t/ha) as compared to other treatments due to lower weed biomass (42.7 and 47.0 g/m2 at 45 and 75 DAP, respectively) and higher weed control efficiency at 45 and 75 DAP (86.4 and 85.5% at 45 and 75 DAP, respectively) during 2015-16. Similar trend was observed in 2016-17.

INTRODUCTION

India is the second largest producer of sugar in the world with over 4 mha of sugarcane growing area. It produces approximately 22 mt of sugar annually. Around 85% sugarcane production of India is from Uttar Pradesh, Maharashtra, Tamil Nadu, Andhra Pradesh, Karnataka and Gujarat (Takalkar and Pawar 2012). Sugarcane crop faces tough competition with weeds during 60 to 120 days of its planting which causes heavy reduction in cane yield ranging from 40-67% (Shauhan and Srivastava 2002). Widely spaced crop of sugarcane allows wide range of weed flora to grow profusely in the interspaces between the rows. Frequent irrigations and fertilizer application during early growth stages, increase the weeds menace by many folds in the crop (Singh *et al.* 2008).

It is well-established that cultural method of weed management is most effective to control weeds but timely availability of agricultural labours is a problem. Herbicidal control of weeds has been suggested to be economical in sugarcane (Chaudhari *et al.* 2016). Several herbicides were tried in sugarcane with varying degree of success but the information on the combined use of herbicides along with inter cultivation are scarce. The present investigation was undertaken to study the effect of weed control treatments on growth and yield of sugarcane and its associated weeds.

MATERIALS AND METHODS

An experiment was conducted during 2015-16 and 2016-17 at Agricultural Research Station, Dhadesugur, University of Agricultural Sciences, Raichur, Karnataka. The soil of the experimental site was black soil and the pH (8.04), EC (0.47 ds/m), medium in organic carbon content (0.41%), low in nitrogen (189 kg/ha), medium in phosphorus (58.5 kg/ha) and potassium (287.5 kg/ha). Six treatments *viz.* pyrazosulfuron-ethyl 1% + metribuzin 35% + 2,4-D sodium salt 44% WDG (3000 g/ha), pyrazosulfuron-ethyl (30 g/ha), 2,4-D sodium salt (2.6 kg/ha), metribuzin (1.4 kg/ha), hand weeding at 30 and 60 days after planting (DAP) and weedy check were tested in a randomized block design with four replications. All herbicides were applied at 25 DAP of sugarcane (3 to 4 active leaf weed stage). Herbicides were applied as per the treatments with spray volume of 500 l/ha. One inter cultivation and earthing up at 90 DAP was common for all the treatments. Three budded setts of sugarcane variety '*Co-86032*' were planted in first week of November 2015 and 2016 and harvested in the third week of December 2016 and 2017.

Species wise, weed density was recorded at 15 DAP, 45 DAP and 75 DAP using quadrat of 1.0 m^2 from three randomly selected spots in each plot. Further, total weed biomass was recorded at 45 DAP and 75 DAP for calculating per cent weed control efficiency (WCE). Weed control efficiency (WCE) was calculated as follows.

Weed biomass in weedy check

Millable cane yield was recorded plot wise and expressed as millable cane yield per hectare. The data of each year was analysed separately. MSTAT was used for statistical analysis of data and means were separated using critical difference (CD) at p=0.05. The weed density and biomass values were transformed by square root transformation by adding 1.0 to original values before being subjected to ANOVA (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

The dominant weeds in experimental field were *Echinochloa* spp. *(E. crus-galli* and *E. colona), Dactyloctenium aegyptium, Eleusine indica, Brachiaria* spp. *(B. mutica* and *B. ramosa)* and *Digitaria sanguinalis* among grasses, *Eclipta alba, Chenopodium album, Physalis minima, Ageratum conyzoides, Parthenium hysterophorus* and *Portulaca oleracea* among broad-leaved weeds and *Cyperus* spp. *(C. rotundus* and *C. iria)* among sedges.

Post-emergence application of pyrazosulfuron-ethyl 1% + metribuzin 35% + 2,4-D sodium salt 44% WDG (3000 g/ha) was on at par with twice hand weeded check (**Table 1**), but significantly superior to metribuzin (2000 g/ha), 2,4-D sodium salt (3250 g/ha) and pyrazosulfuron-ethyl (300 g/ha) in terms of reducing weed density. Similar trend was observed in 2016-17 (**Table 2**).

Table 1. Effect of weed control treatments on weed density (no./m^2) in sugarcane (1st season-2015-16)

Treatment	Grasses			Broad-leaved weeds			Sedges		
	15 DAP	45 DAP	75 DAP	15 DAP	45 DAP	75 DAP	15 DAP	45 DAP	75 DAP
Pyrazosulfuron-ethyl + metribuzin + 2,4-D sodium salt WDG (3000 g/ha)	15.3 (4.03)	2.48 (1.87)	3.08 (2.02)	13.8 (3.85)	1.31 (1.52)	1.62 (1.62)	1.25 (1.50)	0.16 (1.08)	0.20 (1.09)
Pyrazosulfuron-ethyl (300 g/ha)	14.20 (3.90)	21.23 (4.71)	26.5 (5.25)	13.53 (3.81)	9.50 (3.24)	11.9 (3.59)	1.42 (1.56)	2.25 (1.80)	2.81 (1.95)
2,4-D sodium salt (3250 g/ha)	13.8 (3.85)	20.92 (4.68)	30.29 (5.59)	15.7 (4.08)	11.77 (3.57)	14.8 (3.98)	1.25 (1.50)	6.25 (2.69)	7.88 (2.98)
Metribuzin (2000 g/ha)	13.8 (3.85)	10.26 (3.36)	12.7 (3.70)	15.4 (4.05)	10.60 (3.41)	13.1 (3.76)	1.67 (1.63)	4.52 (2.35)	5.60 (2.57)
Hand weeding at 30 and 60 DAP	14.6 (3.94)	5.13 (2.48)	6.16 (2.68)	15.5 (4.07)	1.86 (1.68)	2.88 (1.97)	1.25 (1.50)	0.12 (1.06)	0.14 (1.07)
Weedy check	16.5 (4.19)	32.8 (5.81)	39.3 (6.35)	15.9 (4.11)	30.64 (5.62)	36.8 (6.15)	1.65 (1.63)	7.25 (2.87)	8.70 (3.11)
LSD (p=0.05)	NS	0.65	0.65	NS	0.52	0.89	NS	0.42	0.53

Figures in the parentheses are square root transformed values ($\sqrt{x+1}$); DAP: Days after planting

Table 2. Effect of weed control treatments on weed density (no/m^2) in sugarcane (2nd season-2016-17)

Treatment	Grasses			Broad-leaved weeds			Sedges		
	15 DAP	45 DAP	75 DAP	15 DAP	45 DAP	75 DAP	15 DAP	45 DAP	75 DAP
Pyrazosulfuron-ethyl + metribuzin + 2,4-D sodium salt WDG (3000 g/ha)	14.3 (3.91)	1.75 (1.66)	2.19 (1.79)	12.8 (3.71)	1.34 (1.53)	1.68 (1.64)	1.20 (1.48)	0.19 (1.09)	0.24 (1.11)
Pyrazosulfuron-ethyl (300 g/ha)	12.74 (3.71)	20.47 (4.63)	29.3 (5.50)	13.1 (3.76)	9.53 (3.24)	13.6 (3.82)	2.52 (1.88)	2.27 (1.81)	3.25 (2.06)
2,4-D sodium salt (3250 g/ha)	12.5 (3.67)	23.11 (4.91)	30.91 (5.65)	13.5 (3.81)	11.75 (3.57)	14.45 (3.93)	1.20 (1.48)	6.21 (2.69)	7.64 (2.94)
Metribuzin (2000 g/ha)	11.4 (3.52)	11.73 (3.57)	14.3 (3.91)	12.3 (3.64)	10.61 (3.41)	12.9 (3.73)	1.52 (1.59)	4.12 (2.26)	5.03 (2.45)
Hand weeding at 30 and 60 DAP	12.8 (3.72)	6.12 (2.67)	7.34 (2.89)	11.7 (3.56)	1.94 (1.71)	4.08 (2.25)	1.20 (1.48)	0.16 (1.08)	0.19 (1.09)
Weedy check	14.7 (3.96)	31.08 (5.66)	37.3 (6.19)	13.9 (3.85)	30.23 (5.59)	36.3 (6.11)	1.45 (1.57)	6.87 (2.81)	8.24 (3.04)
LSD (p=0.05)	NS	0.81	1.25	NS	0.62	0.89	NS	0.52	0.56

Figures in the parentheses are square root transformed values ($\sqrt{x+1}$); DAP: Days after planting

Similarly, hand weeding twice at 30 and 60 DAP recorded significantly lower weed biomass and higher weed control efficiency, which was on a par with the post-emergence application of pyrazosulfuron-ethyl 1% + metribuzin 35% + 2,4-D sodium salt (3000 g/ha) compared to application of metribuzin (2000 g/ha), 2,4-D Sodium salt (3250 g/ha) and pyrazosulfuron-ethyl (300 g/ha) during the both the years (**Table 3 and 4**).

Table 3. Weeds biomass (g/m^2) and WCE as affected by different treatments in sugarcane (1st season-2015-16)

Treatment	Weed biomass (g/m^2) at 45 DAP				WCE	Weed biomass (g/m^2) at 75 DAP				WCE
	Grasses	BLW	Sedges	Total	(%)	Grasses	BLW	Sedges	Total	(%)
Pyrazosulfuron-ethyl + metribuzin + 2,4-D sodium salt WDG (3000 g/ha)	18.5 (4.42)	15.5 (4.06)	8.7 (3.11)	42.7 (6.61)	86.4	21.5 (4.74)	16.2 (4.15)	9.3 (3.20)	47.0 (6.92)	85.5
Pyrazosulfuron-ethyl (300 g/ha)	98.5 (9.97)	18.5 (4.42)	14.2 (3.90)	131.2 (11.5)	58.2	102.5 (10.17)	19.2 (4.49)	14.8 (3.97)	136.5 (11.73)	57.8
2,4-D sodium salt (3250 g/ha)	100.2 (10.06)	21.8 (4.77)	45.2 (6.80)	167.2 (12.97)	46.7	105.0 (10.30)	26.5 (5.24)	46.8 (6.91)	178.3 (13.39)	44.8
Metribuzin (2000 g/ha)	51.00 (7.21)	18.5 (4.42)	42.8 (6.62)	112.3 (10.6)	64.2	55.2 (7.50)	25.2 (5.12)	43.2 (6.65)	123.6 (11.16)	61.8
Hand weeding at 30 and 60 DAP	14.0 (3.87)	10.5 (3.39)	3.5 (2.12)	28.0 (5.39)	91.1	15.2 (4.02)	11.2 (3.49)	4.3 (2.29)	30.7 (5.63)	90.5
Weedy check	148.6 (12.23)	105.0 (10.30)	60.3 (7.83)	313.9 (17.7)	-	152.5 (12.39)	108.5 (10.5)	62.3 (7.96)	323.3 (18.01)	-
LSD (p=0.05)	0.85	0.64	0.71	1.21	5.24	0.84	0.42	0.65	0.92	6.21

Figures in the parentheses are square root transformed values ($\sqrt{x+1}$); DAP: Days after planting; BLW = Broad-leaved weeds

Table 4. Weed biomass (g/m2) and weed control efficiency (WCE) as affected by treatments in sugarcane (2nd season-2016-17)

Treatment	Weed biomass (g/m^2) at 45 DAP				WCE (%)	Weed biomass (g/m^2) at 75 DAP				WCE (%)
	Grasses	BLW	Sedges	Total		Grasses	BLW	Sedges	Total	
Pyrazosulfuron-ethyl + metribuzin + 2,4-D sodium salt WDG (3000 g/ha)	15.8 (4.10)	13.2 (3.77)	7.1 (2.85)	36.1 (6.09)	87.1	17.2 (4.27)	12.5 (3.68)	6.8 (2.79)	36.5 (6.12)	86.3
Pyrazosulfuron-ethyl (300 g/ha)	99.2 (10.0)	19.4 (4.52)	15.1 (4.01)	133.7 (11.6)	52.2	103.5 (10.22)	19.8 (4.56)	15.3 (4.04)	138.6 (11.82)	47.9
2,4-D sodium salt (3250 g/ha)	97.8 (9.94)	20.2 (4.60)	46.8 (6.91)	164.8 (12.88)	41.1	99.0 (10.00)	19.2 (4.49)	47.8 (6.99)	166 (12.92)	40.7
Metribuzin (2000 g/ha)	54.1 (7.42)	18.5 (4.42)	43.5 (6.67)	116.1 (10.82)	58.5	57.5 (7.65)	18.5 (4.42)	46.2 (6.87)	122.2 (11.10)	56.4
Hand weeding at 30 and 60 DAP	12.6 (3.69)	8.2 (3.03)	4.2 (2.28)	25.0 (5.10)	91.1	12.0 (3.60)	5.0 (2.45)	4.0 (2.23)	21.0 (4.69)	92.1
Weedy check	132.5 (11.6)	93.2 (9.71)	54.3 (7.43)	280.0 (16.8)	-	125.9 (11.26)	88.5 (9.46)	51.6 (7.25)	266.0 (16.34)	-
LSD (p=0.05)	0.52	0.68	0.74	0.98	4.98	0.58	0.68	0.84	0.74	7.24

Figures in the parentheses are square root transformed values ($\sqrt{x+1}$); DAP: Days after planting; BLW = Broad-leaved weeds

Table 5. Sugarcane yield and yield attributes as affected by different herbicidal treatments

Treatment	1st season-2015-16				2nd season –2016-17			
	No. of millable canes/ha	Length of millable cane (cm)	Cane diameter (cm)	Cane yield (t/ha)	No. of millable canes/ha	Length of millable cane (cm)	Cane diameter (cm)	Cane yield (t/ha)
Pyrazosulfuron-ethyl + metribuzin + 2,4-D sodium salt WDG (3000 g/ha)	95963	255.3	3.01	119.5	97521	260.1	3.05	122.7
Pyrazosulfuron-ethyl (300 g/ha)	93652	245.6	2.95	110.2	95325	250.2	2.98	111.2
2,4-D sodium salt (3250 g/ha)	93021	241.3	2.85	105.2	94125	245.2	2.85	106.2
Metribuzin (2000 g/ha)	93125	242.3	2.91	108.5	94250	248.1	2.95	109.5
Hand weeding at 30 and 60 DAP	98000	261.5	3.13	121.0	99500	265.5	3.14	125.5
Weedy check	58000	231.5	2.77	75.2	58900	225.3	2.74	76.2
LSD (p=0.05)	2138	7.32	0.14	1.52	1824	6.45	0.10	1.35

DAP= Days after planting

On an average, weeds competition throughout the crop period caused 38.5% reduction in the millable cane yield when compared with hand weeding twice at 30 and 60 DAP (**Table 5**). Singh *et al.* (2012**)** stated that, on an average, presence of total weeds throughout the crop period caused 55.94% reduction in the ratoon cane yield. Post-emergence application of pyrazosulfuron-ethyl + metribuzin + 2,4-D sodium salt (3000 g/ha) recorded significantly the highest number of canes (95963/ha, 97521/ha), length of millable cane (255.3 cm, 260.1 cm), cane diameter (3.01 cm, 3.05 cm) and higher millable cane yield (119.5 t/ha, 122.7 t/ha) during 2015-16 and 2016-17.

It was concluded that application of pyrazosulfuron-ethyl p + metribuzin p + 2,4-D Sodium salt p (3000 g/ha) at 20-25 DAP followed by one intercultivation and earthing up at 90 DAP was most effective for managing weeds in sugarcane.

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Sequential application of herbicides for control of weeds in rainfed Bt cotton

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ABSTRACT

A field experiment was carried out for two consecutive years at the Research farm of Regional Agricultural Research Station, Nandyal during *Kharif* 2016-17 and 2017-18 with an objective to find out the effective and economic method of weed control in Bt cotton. Among different herbicide applications, pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing at 50 DAS were significantly superior in reducing weed density and dry weight of weeds. The crop growth parameters (plant height, no of sympodia per plant), yield attributes (no. of bolls/m^2 andboll weight) and seed cotton yield were recorded highest in weed free check (4.18 t/ha in 2016 and 3.23 t/ha in 2017) and was comparable with pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing at 50 DAS. However, the lowest seed cotton yield was recorded under weedy check plot (1.62 t/ha in 2016 and 1.64 t/ha in 2017). Among weed control treatments, highest B:C ratio was recorded with application of pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed+ one hoeing at 50 DAS closely *fb* weed free check.

INTRODUCTION

Cotton being a wide spaced and relatively slow growing crop during its initial growth stages, suffers from severe weed competition and causing substantial reduction in seed cotton yields upto an extent of 69 per cent (Srinivasulu and Rao 2000). Weed species in cotton field differ widely due to soil and environmental conditions. Weed control, especially during the first eight weeks of cotton growth is essential due to the vulnerability of cotton to early season weed competition. So, use of herbicides is one of the best options to avoid the competition from weeds during the critical period of crop growth. Most often due to incessant rains during *Kharif* season, hand weeding and intercultivation (IC) become difficult in cotton. Further, labours being scarce and costly, growers are forced to fall back on chemicals for weed control. Pre- emergence herbicides at recommended doses are generally capable of controlling annual weeds up to a period of 30 days (Pawar *et al*. 2000). Concentration of these herbicides in soil decreases due to the short half life of herbicide molecules leading to emergence of susceptible weed species beyond 30 days after application of herbicides. In the absence of intercultural and with regular monsoon rains, weeds germinate in different spells and compete with crop plants and finally reduce the seed cotton yield. Hence, there is a need to go for sequential application of pre- emergence followed by post-emergence herbicides to manage the late emerging weeds to eliminate weed competition throughout the critical period (Pawar *et al.* 2000).

Several workers tested the use of post-emergence herbicides like pyrithiobac-sodium (Rao 2011), glyphosate, quizalofop-ethyl (Prabhu *et al.* 2011 and Rao 2011) either alone or in combination. The primary mode of action of pendimethalin is to prevent plant cell division and elongation in susceptible species. Pyrithiobac-sodium inhibits Acetolactase synthase, a key enzyme inbiosynthesis of branched chain amino acids. The productivity of seed cotton in India is 504 kg/ha which is below the world average of 792 kg/ha. In Andhra Pradesh, the cotton crop is being grown in an area of 0.544 million ha with the productivity of 688 kg/ha (Annual Report, AICRP on cotton, 2017-18). This crop is mostly grown in Vertisols of Andhra Pradesh. Hence, present investigation was conducted to study the economics of rainfed Bt cotton as influenced by sequential application of herbicides.

MATERIALS AND METHODS

The field experiment was carried out for two consecutive years at the Research farm of Regional Agricultural Research Station, Acharya N.G Ranga Agricultural University, Nandyal, Andhra Pradesh situated at an altitude of 216 m above mean sea level at 15°29'19'' N latitude and 78° 29'11'' E longitude during *Kharif*, 2016 and 2017 with an a objective to find out the effective and economic method of weed control in Bt cotton. The experiment consists of nine treatments involving various weed management practices in a randomized block design with three replications. The details of treatments were pendimethalin 1.0 kg/ha as pre-emergence + one hoeing, tank mixture (quizalofop-ethyl 50 g/ha+ pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing, chlorimuron-ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing, pendimethalin1.0 kg/ha as pre-emergence + cover crop with sorghum sown at 20 DAS of cotton, pendimethalin 1.0 kg/ha as pre-emergence+ glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing, pendimethalin 1.0 kg/ha as pre-emergence *fb* tank mixture (quizalofop-ethyl 50 g/ha+ pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing , pendimethalin 1.0 kg/ha as pre-emergence *fb* chlorimuron-ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing, weed free check, weedy check.

The experimental site was deep black clay in textural class with low organic carbon (0.39%) and available nitrogen (188.6 kg/ha), medium in available phosphorus (23.6 kg/ha) high in available potassium (480.0 kg/ha) with P_H (8.3), EC (0.09 ds/m). Good viable delinted seeds of '*Jaddoo BG-II*' were dibbled with a spacing of 90 × 45 cm during July. The seed rate adopted was 2.5 kg of delinted seeds/ha. The experimental plots were applied with recommended dose of fertilizers (150:60:60 NPK kg/ha). The entire dose of phosphorus was applied as basal in the form of single super phosphate (16% P_2 O_5). Nitrogen in the form of urea (46% N) and potassium (60% K_2O) in the form of muriate of potash were applied in three equal splits at 30,60 and 90 DAS by pocketing method. Herbicides were applied with hand operated knapsack sprayer using a spray volume of 500 l/ha. A total of 800 mm rainfall was received during both the years of study. Pre-emergence herbicides were applied immediately after sowing at proper moisture levels in the soil. Post-emergence herbicides were applied at specified time interval as per the scheduled programme. Weed count was recorded at 30, 60 and 90 DAS using quadrate from each plot and expressed per m^2 and data was subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis to normalize the distribution (Panse and Sukhatme 1978). Weed dry weight was recorded after drying the weed samples at 70^0C for 48 h. Weed control efficiency was computed as prescribed by Mani *et al.* (1973) and expressed as percentage. Plant height (cm), number of sympodia per plant, number of bolls/m^2, boll weight (g) were recorded just before harvesting. Three pickings of seed cotton was done from each treatment for recording final yield data.

RESULTS AND DISCUSSION

Weed flora of the experimental field predominantly consisted of six species of broad-leaved weeds, two species of grasses and a sedge. Dominant among grassy weeds were *Panicum repens* (8.3%) and *Dianebra retroflexa* (6.2%). *Euphorbia hirta* (8.0%), *Trianthema portulacastrum* (20.2%), *Cyanotis auxalis* (8.2%), *Digera arvensis* (9.5%), *Abutilon indicum* (10.0%) and *Phyllanthus maderaspatensis* (22.6%) were the dominant broad-leaved weeds. *Cyperus rotundus* (7.0%) was the only sedge present in the experimental fields.

Weed density

All the weed management practices influenced the weed density in cotton in both the years. At 30 DAS, highest weed density was recorded with tank mixture of quizalofop-ethyl 50 g/ha+ pyrithiobac-sodium 62.5 g/ha at 2-4 leaf stage weed + one hoeing, which was comparable with chlorimuron ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing. Significantly lower weed density was recorded with pendimethalin 1.0 kg/ha as pre-emergence *fb* tank mixture of quizalofop-ethyl 50 g/ha+ pyrithiobac-sodium 62.5 g/ha at 2-4 leaf stage weed + one hoeing at 50 DAS, which was comparable with all other treatments expect weed free check because of the post-emergence spray at 20 DAS which effectively controlled the weeds and resulted in low weed density at 30 DAS. Almost similar trend was noticed in second year of study in which all the sequential applications were on par with each other. At 60 DAS, higher weed density was observed with pendimethalin 1.0 kg/ha as pre-emergence+ one hoeing treatment and lower weed density was recorded with pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing at 50 DAS, which was comparable with pendimethalin 1.0 kg/ha as pre-emergence *fb* tank mixure (quizalofop-ethyl 50 g/ha + pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing and tank mixure (quizalofop-ethyl 50 g/ha+ pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing treatment during both the years of study. At 90 DAS pendimethalin 1.0 kg/ha as pre-emergence + one hoeing treatment recorded higher weed density, which was comparable with chlorimuron-ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing, while lower weed density was noticed with pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing at 50 DAS and on par with other treatments (**Table 1**).

Critical review of the data indicates that sequential application of pre-emergence herbicides *fb* post-emergence application of glyphosate or tank mixture of quizalofop-ethyl + pyrithiobac-sodium reduced the weed density considerably and resulted in lowest weed density among these treatments. The better performance of sequential application might be due to the effective control of weeds at critical stages. The present findings were in conformity with the findings of Singh *et al*. (2003) and Sonawane *et al*. (2014).

Total weed dry matter

Total weed dry matter was recorded at 30, 60 and 90 DAS during both the years of investigation. At 30 DAS all pre-emergence herbicidal treatments were significantly superior over post-emergence herbicides and weedy check. At 60 DAS higher weed dry weight (19.7 g in 2016 and 21.0 g in 2017) was recorded with pendimethalin 1.0 kg/ha as pre-emergence+ one hoeing treatment and significantly lowest weed density was recorded with pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed+ one hoeing at 50 DAS. This could be attributed to reduced weed competition in the initial stage and control of late emerged weeds by sequential spray which lead to lower weed density and lower weed dry matter. Similar findings were reported by Patel *et al*. (2006) and Ahmed and Susheela (2012). At 90 DAS higher weed dry weight (58.0 g in 2016 and 62.0g in 2017) with chlorimuron ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing and lowest weed density (16.2 g in 2016 and 16.0 g in 2017) was recorded with pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed+ one hoeing at 50 DAS (**Table 2**).

Weed control efficiency

The weed dry weight was markedly reduced due to application of pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing at 50 DAS, which resulted in higher weed control efficiency (62.0% in 2016 and 63.9% in 2017), which was comparable with that of weed free check (93%). The better performance of these herbicides might be due to the effective control of all type of weeds by the pre-emergence herbicide during initial stages *fb* control of all type of weeds by spraying the directed application of glyphosate due to its systemic action and it made a cover of killed weeds on soil surface which did not allow new weeds to emerge and provided season long control of weeds. This finding is in line with the results of Gnanavel and Babu (2008) (**Table 2**).

Table 1. Weed density as influenced by different weed control treatments

Treatment	Weed density (no./m^2)					
	30 DAS		60 DAS		90 DAS	
	2016	2017	2016	2017	2016	2017
Pendimethalin 1.0 kg/ha as pre-emergence + one hoeing	4.2* (18.0)	4.0 (16.3)	5.4 (29.7)	5.5 (30.3)	6.9 (48.3)	7.3 (53.0)
Tank mixure (quizalofop-ethyl 50 g/ha + pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing.	7.2 (52.2)	7.3 (53.7)	3.6 (12.7)	3.4 (11.7)	6.4 (40.7)	6.6 (43.2)
Chlorimuron ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing	6.8 (47.6)	6.8 (46.3)	4.2 (18.0)	4.3 (18.3)	6.5 (42.3)	6.4 (41.2)
Pendimethalin 1.0 kg/ha as pre-emergence + cover crop with sorghum sown at 20 DAS of cotton	4.5 (20.3)	4.7 (22.3)	3.9 (15.3)	3.8 (14.7)	6.4 (40.7)	7.0 (48.3)
Pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing	4.4 (19.7)	4.3 (18.3)	3.4 (11.3)	3.5 (12.0)	5.8 (34.0)	5.7 (32.0)
Pendimethalin 1.0 kg/ha as pre- emergence *fb* tank mixure (quizalofop-ethyl 50 g/ha + pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing	4.2 (17.7)	4.2 (17.7)	3.6 (13.0)	3.8 (14.7)	6.2 (38.0)	6.0 (36.0)
Pendimethalin 1.0 kg/ha as pre- emergence *fb* chlorimuron-ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing	4.3 (18.3)	4.6 (21.0)	3.9 (15.3)	4.5 (20.3)	6.2 (38.0)	6.2 (38.3)
Weed free check	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)
Weedy check	7.0 (49.7)	7.4 (54.3)	9.2 (84.7)	9.1 (83.3)	10.3 (107.6)	10.6 (111.3)
LSD (p=0.05)	4.9	4.9	3.8	4.2	6.0	6.5

Crop growth parameters

Plant biometric parameters such as plant height and number of sympodia were significantly influenced by weed control treatments during both the years of study. The cotton plants were taller (133.6 cm in 2016 and 156.3 cm in 2017) in weed free check, which was comparable with all the treatments except weedy check (**Table 3**). Excessive vegetative growth was observed during second year due to continuous rainfall in August. Higher number of sympodia per plant was recorded with weed free check, which was comparable with all the treatments except chlorimuron ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing.

Yield attributes and yield

The data on yield attributes like number of bolls per square meter and boll weight indicate that the application of pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed+ one hoeing at 50 DAS reduced the weed competition and facilitated the crop plants to utilize the resources like water and nutrients available and resulted in better crop growth, better yield attributes like more number of bolls per square meter and increased boll weight (g) and finally highest seed cotton yield.

Table 2. Weed dry weight and weed control efficiency (WCE) as influenced by different weed control treatments

Treatment	Weed dry weight (g/m^2) 30 DAS 2016	30 DAS 2017	60 DAS 2016	60 DAS 2017	90 DAS 2016	90 DAS 2017	WCE at 90 DAS (%) 2016	WCE at 90 DAS (%) 2017
Pendimethalin 1.0 kg/ha as pre-emergence + one hoeing	3.5* (12.5)	3.3 (10.7)	4.4 (19.7)	4.6 (21.0)	6.9 (48.0)	7.3 (53.3)	34	34.2
Tank mixure (quizalofop-ethyl 50 g/ha+ pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing.	7.3 (52.8)	7.0 (48.7)	3.5 (12.1)	3.9 (15.3)	4.8 (22.7)	4.6 (21.3)	54.3	58.5
Chlorimuron ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing	7.4 (54.3)	6.8 (46.7)	4.2 (17.5)	4.0 (15.7)	7.6 (58.0)	7.9 (62.0)	27.6	28.8
Pendimethalin 1.0 kg/ha as pre-emergence + cover crop with sorghum sown at 20 DAS of cotton	3.6 (13.3)	3.5 (12.3)	3.6 (13.2)	3.5 (12.0)	5.6 (31.4)	6.0 (35.7)	46.6	45.9
Pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing	3.8 (14.5)	3.7 (13.7)	3.3 (10.7)	3.3 (11.0)	4.0 (16.1)	4.0 (16.0)	62.0	63.9
Pendimethalin 1.0 kg/ha as pre- emergence *fb* tank mixure (quizalofop-ethyl 50 g/ha + pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing	3.8 (14.3)	3.8 (14.7)	4.0 (15.8)	3.8 (14.7)	6.2 (39)	6.0 (35.7)	41.0	45.9
Pendimethalin 1.0 kg/ha as pre- emergence *fb* chlorimuron-ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing	3.6 (13.2)	3.8 (14.3)	4.1 (16.7)	4.0 (15.7)	6.3 (40)	6.5 (42.5)	40.0	41.4
Weed free check	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	93.3	93.6
Weedy check	7.2 (51.7)	7.3 (52.9)	9.4 (87.6)	9.1 (82.3)	10.5 (109.6)	11.1 (124.0)	0	0
LSD (p=0.05)	3.4	4.7	2.1	3.6	6.3	6.5		

*Data were subjected to square root formation $(\sqrt{x+1})$. Data given in parentheses are original value. DAS- Days after sowing

Table 3. Growth characters and Seed cotton yield as influenced by different weed control treatments

Treatment	Plant height (cm) 2016	Plant height (cm) 2017	No. of sympodia at harvest 2016	No. of sympodia at harvest 2017	No. of Bolls/m^2 2016	No. of Bolls/m^2 2017	Boll weight (g) 2016	Boll weight (g) 2017	Seed cotton yield (t/ha) 2016	Seed cotton yield (t/ha) 2017
Pendimethalin 1.0 kg/ha as pre-emergence + one hoeing	120.3	146.7	17.1	14.8	66.3	47.0	4.76	4.37	3.21	2.20
Tank mixure (quizalofop-ethyl 50 g/ha + pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing.	124	132.0	19.3	15.5	60.0	46.0	5.02	4.02	2.70	2.23
Chlorimuron-ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing	124	137.7	15.8	16.3	61.6	44.4	4.18	4.02	2.61	2.31
Pendimethalin 1.0 kg/ha as pre-emergence + cover crop with sorghum sown at 20 DAS of cotton	122.2	143.3	16.2	17.3	65.3	53.5	4.74	4.33	3.13	2.06
Pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing	128.0	144.7	20.0	18.0	79.6	61.0	5.15	4.43	4.18	2.78
Pendimethalin 1.0 kg/ha as pre-emergence *fb* tank mixure (quizalofop-ethyl 50 g/ha + pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing	126.3	136.3	19.1	16.7	69.8	56.7	5.12	4.37	3.62	2.70
Pendimethalin 1.0 kg/ha as pre-emergence *fb* chlorimuron-ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing	122.6	132.0	19.1	15.7	68.3	52.1	4.82	3.92	3.20	2.25
Weed free check	133.6	156.3	20.3	19.0	80.0	67.8	5.23	4.60	4.18	3.23
Weedy check	92.0	89.3	13.0	13.0	48.0	43.6	3.38	2.97	1.62	1.64
LSD (p=0.05)	17.5	25.8	3.6	2.5	16.7	10.4	0.8	0.86	0.72	0.54

Table 4. Economics as influenced by different weed control treatments

Treatment	Cost of weeding (x10^3 `/ha)		Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C ratio	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Pendimethalin 1.0 kg/ha as pre-emergence + one hoeing	6.12	6.42	52.62	53.42	176.71	99.13	124.09	45.71	3.4	1.9
Tank mixure (quizalofop-ethyl 50 g/ha + pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing.	8.47	8.72	54.97	55.72	148.61	100.44	93.63	44.71	2.7	1.8
Chlorimuron ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing	5.27	5.67	51.77	52.67	143.38	103.90	91.61	51.23	2.8	2.0
Pendimethalin 1.0 kg/ha as pre-emergence + cover crop with sorghum sown at 20 DAS of cotton	6.32	6.50	52.82	53.50	172.04	92.74	119.21	39.24	3.3	1.7
Pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing	6.00	6.20	52.50	53.20	229.73	125.01	177.23	71.81	4.4	2.3
Pendimethalin 1.0 kg/ha as pre-emergence *fb* tank mixure (quizalofop-ethyl 50 g/ha + pyrithiobac-sodium 62.5 g/ha) at 2-4 leaf stage weed + one hoeing	9.60	9.80	56.10	56.80	198.93	121.59	142.83	64.79	3.5	2.1
Pendimethalin 1.0 kg/ha as pre-emergence *fb* chlorimuron-ethyl 4.0 g/ha at 2-4 leaf stage weed + one hoeing	6.39	6.89	52.89	53.89	176.00	101.47	123.10	47.58	3.3	1.9
Weed free check	14.00	14.60	60.50	61.60	230.12	145.57	169.62	83.97	3.8	2.4
Weedy check	0	0	46.50	47.00	89.37	73.84	42.87	26.84	1.9	1.6

Seed cotton yield was significantly influenced by the weed control treatments in both the years (**Table 3**). Higher seed cotton yield (4.2 t/ha in 2016 and 3.2 t/ha in 2017) was recorded with weed free check and was on par with pendimethalin1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing at 50 DAS and pendimethalin 1.0 kg/ha as pre-emergence *fb* tank mixture of quizalofop-ethyl 50 g/ha+ pyrithiobac-sodium 62.5 g/ha at 2-4 leaf stage weed + one hoeing (Nayak BS *et al*. 2016). Lower seed cotton yield (1.6 t/ha and 1.6 t/ ha in 2016 and 2017, respectively) was recorded with weedy check.

Higher cost of cultivation (60.5 x10^3 `/ha and 61.6 x10$^3$ `/ha in 2016 and 2017, respectively) was recorded with weed free check and lowest with weedy check. Higher net returns (169.62 x10^3 `/ha and 83.97x10$^3$ `/ha in 2016 and 2017, respectively) and B:C ratio (4.4 and 2.3 in 2016 and 2017, respectively) was recorded with pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing at 50 DAS, which is similar to the trend of weed free check (**Table 4**).

It may be concluded that sequential application of pendimethalin 1.0 kg/ha as pre-emergence *fb* glyphosate 1.0 kg/ha as directed spray at 2-4 leaf stage weed + one hoeing at 50 DAS provide effective and economical weed control during the critical period of crop weed competition in Bt cotton.

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Dynamic strength based dryland weeders – ergonomic and performance evaluation

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ABSTRACT

Human labour is a single costliest input in farming operations. Most of agricultural equipment designers regarded the operator as only another part of man-machine system and neglected their comfortness. Manually operated weeders are of push/pull type weeders, operated by application of force in dynamic motion. But, the existing dryland weeders designed based on static force exertion, even though they are in dynamic nature and require higher amount of force application than static ones. Hence, weeders of straight blade (apex angle 180^0) and V blade (apex angle 90^0) were developed for dryland conditions based on the dynamic strength optimized under laboratory conditions. The ergonomical and field performance evaluation was conducted for developed weeders along with one existing twin wheel hoe. The developed weeders showed an increased field performance in terms of field capacity, weeding efficiency and performance index with minimum physiological responses over twin wheel hoe. There was an increase in weeding efficiency, field capacity and performance index by 5, 21 and 7 percent and 4, 21 and 6 percent for straight and V blade weeders, respectively over twin wheel hoe. Further, the physiological responses such as heart rate, oxygen consumption, energy expenditure, acceptable work load (AWL), limit of continuous performance (LCP), overall discomfort rating (ODR) and body part discomfort score (BPDS) were reduced by 5, 7, 8, 8, 9, 11 and 6 percent for straight blade and 5, 7, 8, 9, 10, 13 and 10 percent for V blade respectively over twin wheel hoe.

INTRODUCTION

Human labour is a single costliest input in farming operations contributing to major part of the total cost of cultivation. Most designers of agricultural equipment regarded the operator as only another part of man-machine system, but none of them seem to concentrate on their comfortness. Hence, there is an urgent need to critically analyse agricultural tools/equipment for their ergonomical design in order to improve man-machine system efficiency without sacrificing the performance. The application of ergonomic principles are more relevant in the present-day situation in terms of providing proper design of hand tools and farm equipment. This will help to develop an appropriate design, labour effective and simpler operational tools. These, designs not only minimize the drudgery of labours, it also increases the productivity and effectiveness at minimized physiological expenditure levels. For ergonomical evaluation of the task, a cardinal principle and oxygen consumption rate of a person can be considered (Rodahl 1989, Kroemer and Grandjean 1997). In addition, perceived responses of the operator also play a major role in ergonomical designs. Weeding with traditional tools like *khurpi* and spade has to be performed in bending/squatting posture and it leads to 30-50 % more energy consumption than sitting or standing posture. These tools requires less energy consumption, but involves repetitive movement of body parts which may lead to musculoskeletal disorders, that outweighs its other advantages (Tewari *et al.* 1993). Whereas the wheel hoes, cover maximum area with the acceptable physiological demand, work performance and workers preference (Nag and Dutta 1979).

Manually operated weeders are of push/pull type, operated by application of force in dynamic motion. Most of the existing weeders designs are based on static force exertions, despite the knowledge that they are in dynamic nature and requires higher strength force compared to static force. However, the dynamic force exertions are lower than the static force exertions and involve higher risk of injuries and health complaints; thus, parameters optimized for static conditions may not be accurate for dynamic conditions (Snook 1978, Lee *et al.* 1991, Resnick and Chaffin 1995, Allread *et al.* 2000). Hence, a dryland weeder based on dynamic strength of agricultural workers has been developed and their performance was evaluated ergonomically in field conditions.

MATERIALS AND METHODS

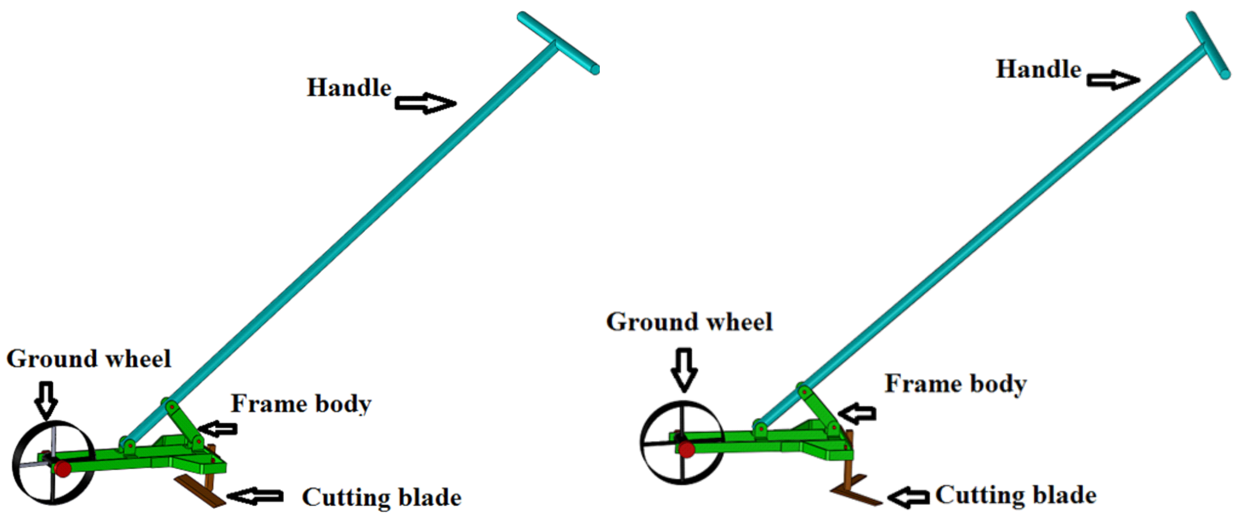
The dynamic push strength of agricultural workers to design the dryland weeders has been optimized to 20 to 25 kgf, at operating speed within 1.0 to 1.5 km/h (Sharma and Mukesh 2010, Chethan and Krishnan 2017). Two types of dryland weeder V and straight blade (S) (apex angle 90^0 and 180^0) having width of cut of 250 mm has developed and their field performance was evaluated ergonomically in comparison with one existing twin wheel hoe having the width of cut of 150 mm **(Figure 1).** The field evaluation of the weeders was conducted at cotton crop research fields, TNAU, Coimbatore (11°00’51.0"N, 76°55’43.4 "E; 11°00’30.4"N, 76°56’24.3"E). Later, based on the performance of the operators during weeding operation, the ergonomic parameters were drawn.

Selection of the subjects

Selection of the subjects plays a vital role in ergonomic evaluation. The subjects should be mentally and physically fit enough to undergo the trials. There should not be any major illness and handicaps and also they should be a true representative of the user population. The maximum strength or power can be expected from the age group of 25 to 35 years (Gite and Singh 1997, Zend *et al.* 2004). Hence, 5 male workers among the population in the mentioned age group were selected considering their expertise in weeding operation for investigation. The subjects were calibrated on the treadmill at different operating load to access their medical fitness under laboratory conditions **(Photo 1)**.

Ergonomical and field performance evaluation of the weeders

Ergonomic evaluation was carried out in terms of heart rate (HR), oxygen consumption rate (VO_2), energy consumption rate (EC), acceptable work load (AWL), limit of continuous performance (LCP), overall discomfort rating (ODR) and body part discomfort score (BPDS) to access the suitability of weeder to the operator. HR and VO_2 are the prominent parameters to access the human energy required to perform the task and there is a close interaction between circulatory and metabolic processes. Thus, by using a computerized ambulatory metabolic measurement system (K4b2) and HR monitors, the physiological responses of the operator can be easily predicted. The recorded values were transferred to the computer through RS232 interface. The



a. Straight blade hoe b. V blade hoe

Figure 1. Schematic diagram of the developed weeders

Photo 1. Laboratory calibration of the subject

physiological responses increases rapidly at the beginning of an exercise and reaches a steady state by the end of sixth minute. The stabilized values of heart rate for each subject from 6th to 15th minute of operation were used to calculate the mean values. Based upon the obtained mean values the Energy consumed, AWL and LCP were calculated. Whereas, the ODR and BPDS are the subjects self reported estimates of effort expenditure, quantified using ratings of perceived exertion. For this, a 10 - point psychophysical rating scale (0 - no discomfort, 10 - extreme discomfort) was used. For BPDS rating scale technique, the subject's body is divided into 27 regions (**Figure 2**).

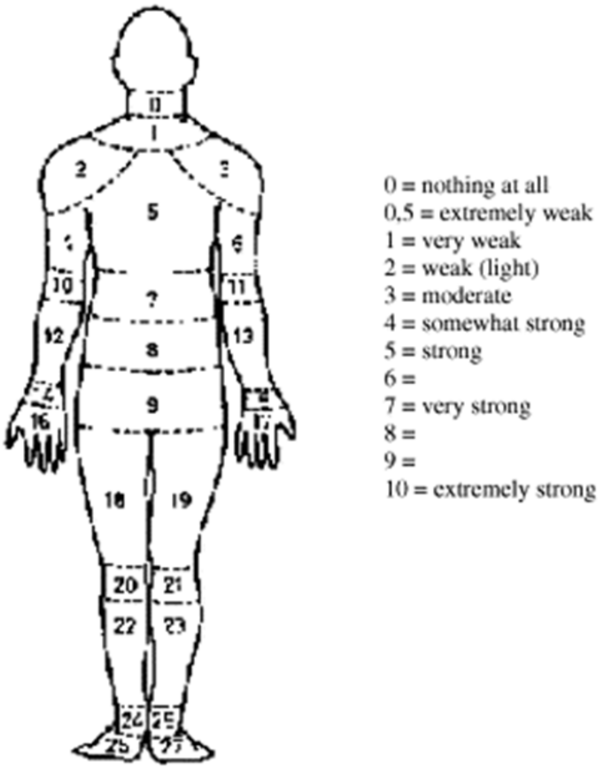


Figure 2. BPDS rating map (Nordic body map)

A body mapping similar to that of body mapping was made with thermocol to have a real and meaningful rating of the perceived exertion of the subject. The subject was asked to mention all body parts with discomfort, starting with the worst, the second worst and so on until all parts have been mentioned and the subjects were asked to give the markings according to the discomfort (Corlett and Bishop 1976, Lusted *et al.* 1994).

The field evaluation of the weeders was conducted to investigate the performance, suitability and comfortability of the weeders to the operator. The evaluation was done for developed weeders in comparison with the existing twin wheel hoe. Weeding efficiency, plant damage, draft force required to operate the weeder, power requirement, filed capacity and performance index are the operational parameters, which are criterion to decide the weeder performance and their suitability. The comparative parameters were also drawn for the selected weeders.

RESULTS AND DISCUSION

Selection of subjects

Five male subjects of group 25 to 35 were selected for ergonomical investigation from the agricultural labour community; medical fitness test was carried out prior to the experiment and details are furnished in **Table 1**. The maximum aerobic capacity of the selected subjects was varied from 1.40 to1.84 l/min (lpm). The varied individual differences in maximum aerobic capacity (VO_2max) was observed due to the differences in the ability to supply oxygen to the muscles and also due to genetic factors (Bridger 1995), whereas, Noakes (1988) suggested that failure of muscle power might be the reason for variation of the VO_2 max among the subjects.

Ergonomical and field performance evaluation of the weeders

Table 1. Details of the subjects participated in the study

Subject	Age (year)	Maximum HR, bpm	Maximum aerobic capacity (VO_2 max), lpm	Stature (mm)	Weight (kg)
S_1	34	186	1.61	165	63
S_2	30	190	1.74	163	74
S_3	36	184	1.55	175	68
S_4	36	184	1.41	168	67
S_5	27	193	1.84	156	56
Mean	32.6	187.4	1.63	165.4	65.6
SD	3.97	3.97	0.17	6.95	6.65

(bpm = beats per minute; lpm = litres per minute)

a. Weeding by developed weeder   b. Weeding by Twin wheel hoe

Photo 2. Weeding operations by different weeders

The ergonomical and field performance evaluation was carried out for all selected weeders (**Photo 2**). The results obtained were depicted in **Table 2 and 3**. During weeding operation the weeders were operated at an average speed of 1.3 km/h. It was noticed that, the developed weeders showed an increased performance in terms of field capacity, weeding efficiency and performance index with minimum physiological responses over twin wheel hoe. The heart rate values of the subjects during operation for developed weeders were comparatively in lower range than the twin wheel hoe (**Figure 3**); the mean heart rate values obtained were 127 beats/min (bpm) for straight blade weeder, 126 bpm for V blade weeder and 133 bpm for twin wheel hoe and corresponding oxygen consumption rate values were 0.92, 0.92 and 0.99 lpm, respectively. The weeding task performed by all the weeders was graded as "*moderately heavy*". The AWL and LCP for weeding operation was varied from 56.20 to 61.80 and 44.47 to 49.27, respectively (**Table 2 and Figure 4**); whereas for twin wheel hoe it was highest.

In general, the work pulse values for weeders showed that, they could not be operated for longer duration without adequate rest since the work pulse values were more than the limit of continuous performance (LCP) of 40 bpm. Whereas, the perceived exertions *i.e.* ODR and BPDS for selected weeders was considered as "more than moderate discomfort" and the values were 6.22 and 39.88, 5.51 and 37.54 and 5.41 and 35.90 for twin wheel hoe, straight blade and V blade weeders, respectively. In weeding with twin wheel hoe, the maximum levels of pain experienced were in 4 categories. The majority of discomfort experienced by the subjects was at right shoulder, left shoulder, clavicle left, clavicle right, left arm, right arm, left elbow, right elbow, left forearm, right forearm, left wrist, right wrist, left palm and right palm. But, this was reduced in case of developed weeders; the maximum pain experienced was in only 3 categories with majority discomfort at right shoulder, left shoulder, clavicle left, clavicle right, left arm, right arm, left wrist and right wrist. This clearly shows that, the developed weeders reduced an operational discomfort (**Figure 4**). Further, the physiological responses of the subjects for developed weeder were much lower and field performance was superior compared to twin wheel hoe. From **Table 3**, it is clearly seen that, there is a considerable increase in performance index (3052.0

Table 2. Physiological responses of the subjects for weeding operation

Parameter	Twin wheel hoe	Developed weeders	
		Straight blade	V blade
Mean heart rate, bpm	133	127	126
Oxygen consumption, lpm	0.99	0.92	0.92
Energy expenditure, kJ/min	20.81	19.18	19.18
AWL, % VO_2 max	61.8	56.8	56.2
LCP, bpm	49.27	44.78	44.47
ODR	6.22	5.51	5.41
BPDS	39.98	37.50	35.90

Table 3. Field performance results of the selected weeders

Parameter	Twin wheel hoe	Developed weeders	
		Straight blade	V blade
Weeding efficiency (%)	92.5	97.8	96.3
Draft force (kg force)	17.75	22.24	22.13
Power requirement (hp)	0.087	0.108	0.107
Field Capacity ($ha\text{-}h^{-1}$)	0.027	0.034	0.034
Performance index (%)	2838	3052	3018

Table 4. Percentage of increase in field performance of the developed weeders over twin wheel hoe

Parameter	Developed weeders	
	Straight blade	V blade
Weeding efficiency	5	4
Draft force	20	20
Power requirement	19	19
Field Capacity	21	21
Performance index	7	6

Table 5. Percentage of reduction in physiological responses of the subjects for developed weeders over twin wheel hoe

Parameter	Developed weeders	
	Straight blade weeder	V blade weeder
Mean heart rate	5	5
Oxygen consumption	7	7
Energy expenditure	8	8
AWL	8	9
LCP	9	10
ODR	11	13
BPDS	6	10

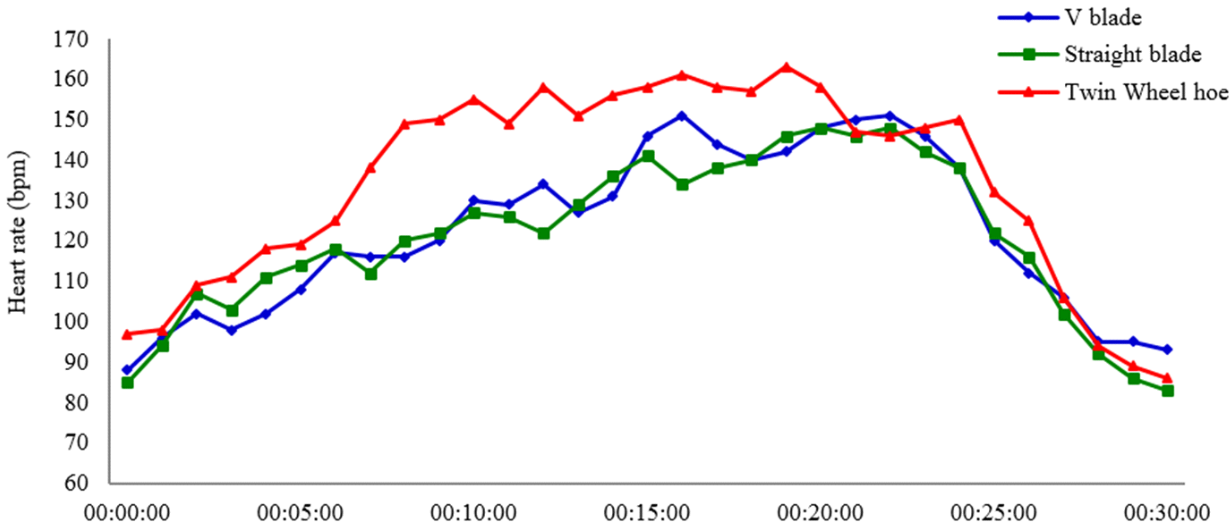


Figure 3. Heart rate responses of the subject for weeding by different weeders

and 3018%) and field capacity (0.034 ha/h each) for straight and V blade weeder over the twin wheel hoe. The energy consumption rate was reduced to19.18 kJ/min (Straight and V blade weeder) from 20.81 kJ/min (twin wheel hoe). Due to the apex angle of 180^0, the weeding efficiency was higher for straight blade weeder; thus, the amount of power required to operate was quite high. Whereas, in V blade weeder, due to the apex angle of 90^0, the blade penetrated easily in to the soil, weed roots slides along the edges of the cutting blade and offered less frictional forces. Thus, the power requirement was quite lower in V blade weeder compared to other weeders. However, the plant damage of 1% was observed in all weeders during weeding operation.

The percentage of increase in field performance and reduction in perceived exertions of the developed weeders over twin wheel hoe are furnished in the **Table 4 and 5**. The draft force and the power requirement to operate the developed weeders increased due to larger width of cut (250 mm) over the twin wheel hoe; however, they showed an

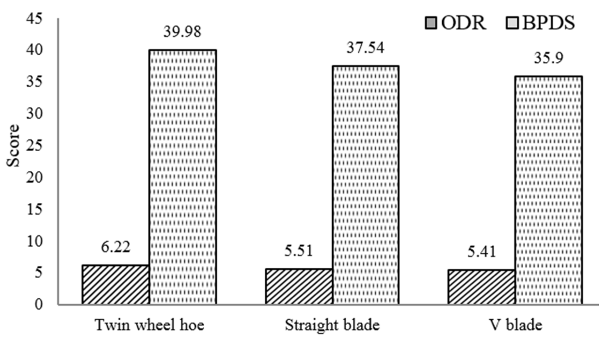


Figure 4. Perceived responses of the subjects for weeding operation

increased field performance with optimum physiological work load over the twin wheel hoe. Weeding by developed weeders enhanced the performance by increasing the weeding efficiency, field capacity and performance index to 5, 21 and 7 percent and 4, 21 and 6 percent for straight and V blade weeders, respectively. But the draft force requirement was increased to 20 percent over twin wheel hoe. Even though the draft force requirement increased there was no compromise in operator comfortness and seen a reduction of 5, 7, 8, 8, 9, 11 and 6 percent for straight blade and 5, 7, 8, 9, 10, 13 and 10 percent for V blade in heart rate, oxygen consumption, energy expenditure, AWL, LCP, ODR and BPDS respectively over twin wheel hoe.

The overall performance of the developed weeders was superior over twin wheel hoe, because of the operational comfort. The weeding operation from the selected twin wheel hoe was so tough for the subjects selected for the experiments. It was because of the anthropometric parameters considered for the twin wheel hoe was not according to the Tamil Nadu agricultural workers; thus created the operational discomfort during the weeding operation. The design parameters of twin wheel hoe such as the curvature of the cross handle bar, handle holding height and elbow angle during the weeding operation were not suited to the subjects, due to which subjects felt discomfort to operate it. Whereas, such problems were rectified in the developed weeders, due to which a good operational comfort and improved physiological responses were obtained even though the operational draft was higher than the twin wheel hoe, which is clearly seen in **Table 2 and 3**. It was obvious that, the developed weeders, *viz*. straight blade and V blade, not only increased the field capacity and performance index but also reduced the physiological work load on operator compared to existing twin wheel hoe.

The design criterion based on dynamic strength capabilities can improve the operational capacity of the operator with optimal physiological work load to perform weeding operation. The developed weeders performed better than the existing twin wheel hoe with minimal physiological responses. However, the performance of the developed V blade weeder was superior over the others due to the blade design.

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Weed management effect in system of rice intensification

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ABSTRACT

A field experiment was conducted at Anbil Dharmalingam Agricultural College and Research Institute, Thiruchirappalli during *Rabi* season 2014-15 to evaluate the weed management practices in system of rice intensification contisted 8 treatments with three replication. Pre-emergence (PE) application of bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 days after transplanting (DAT) *fb* early post-emergence application of bispyribac-sodium at 25 g/ha on 20 DAT registered the minimum total weed density (6.6, 8.8 and 14.3/m^2 at 30, 45 and 60 DAT, respectively) along with higher weed control efficiency (WCE). The highest grain and straw yields of 5.72 and 8.36 t/ha, respectively and net returns and BCR of ` 55436/ha and 2.44, respectively were obtained in application of the same treatment

Rice (*Oryza sativa* L.) is the stable food for more than 60% of the world population. It plays a major role in Indian economy by contributing 45% to the total food grain production in the country. In India, rice is grown in an area of 43.99 million hectares annually with a production of 109.7 million tonnes and an average productivity of 2.5 t/ha (FAO, 2016-17). Productivity of rice in India is declining due to an array of biotic and abiotic factors. Weeds are the prime yield-limiting biotic constraint that competes with rice for moisture, nutrients and light. The problem of weed interference is more in direct-seeded than transplanted rice. Reduction in yield to the tune of 34% in transplanted rice, 45% in direct-seeded low land rice and 67% in upland rice due to weeds have been reported (Muthukrishnan *et al.* 2010).

Most of the farmers in the intensive cropping areas are shifting from conventional transplanting to system of rice intensification (SRI) due to shortage of labour, scarcity of water, energy, *etc*. Cono-weeding is one of the important components in SRI cultivation. Though cono-weeding is considered to be the best, non-availability of labour for cono-weeder and escalating labour cost in many cases have made it imperative to use chemicals for weed control in the SRI. Thus, there is a need to study the chemical weed control in SRI, because of the intensity of weed problems *vis a vis* the scarcity and higher wages of labour for weeding.

A field experiment was conducted at Anbil Dharmalingam Agricultural College and Research Institute, Thiruchirappalli, Tamil Nadu during *Rabi* season 2014-15. The experimental site was located at 10°45' N latitude, 78°36'E longitude and at an altitude of 85 m above mean sea level. A total of 66.1 mm of rainfall in 5 rainy days was received during *Rabi* season in the year 2014-15. The mean minimum and maximum temperatures ranged from 23.1 to 30.3 ^{0}C and the relative humidity ranged from 95.9 to 71.9 per cent during the crop growth period. The experimental soil was sandy clay loam in texture belonging *Vetric Ustropept* with pH of 8.8 and EC of 1.1 dS/m. The experimental soil was low in available nitrogen (229 kg/ha), medium in available phosphorus (14.5 kg/ha) and high in available potassium (288 kg/ha). The experiment was laid out in a randomized block design with eight treatments **(Table 1)** in three replications. The variety used for the experiment was '*TNAU Rice TRY 3*'.

Weed density and total weed dry weight was recorded at 30,45 and 60 days after transplanting (DAT) by adopting standard procedure. The weed control efficiency (WCE) was computed by using the formula as suggested by Mani *et al.* (1973). The yield parameters *viz.* productive tillers/m^2, grains/panicle, panicle length and 1000- grain weight and yield of rice were recorded at harvest stage. Economics of weed management was worked out by using the current market price of inputs and rice grain.

Effect on weeds

The weed flora observed in the experimental field during the course of study consisted of grasses, sedges and broad-leaved weeds. The major grass weeds were *Echinochloa crus-galli* (L.) and *Echinochloa colona* (L.) and the common sedges included *Cyperus difformis* (L.), *Cyperus iria* (L.) and *Fimbristylis miliacea* (L.). Among the broad-leaved weeds, *Eclipta alba* (L.), *Ammania baccifera* (L.) *Marsilea quadrifoliata* (L.), *Monochoria vaginalis* (Burm.f.), *Bergia capensis* (L.) and *Ludwigia parviflora (*Roxb.) were the dominant species.

Pre-emergence (PE) application of bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* early post-emergence application of bispyribac-sodium at 25 g/ha on 20 DAT registered the minimum total weed density (6.6, 8.8 and 14.3/m^2 at 30, 45 and 60 DAT, respectively) and total weed dry weight (1.72, 2.35 and 4.58 g/m^2 at 30, 45 and 60 DAT, respectively) along with higher weed control efficiency (WCE) followed by weeding with cono-weeder at 10, 20, 30 and 40 DAT and pre-emergence application of bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* weeding with conoweeder at 20 and 30 DAT **(Table 1)**. The highest total weed density and total weed dry weight were recorded in un-weeded control. These results were in accordance with the findings of Veeraputhiran and Balasubramanian (2012), Murali *et al.* (2012) and Nalini *et al.* (2012).

The weed control efficiency at all stages of observation was higher with pre-emergence bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* bispyribac-sodium at 25 g/ha on 20 DAT followed by weeding with cono-weeder at 10, 20, 30 and 40 DAT **(Table 1)**. This was due to reduced weed population and weed dry weight which resulted in increased weed control efficiency.

Effect on rice

The yield contributing characters, *viz.* productive tillers and grains/panicle were significantly influenced by weed management practices **(Table 2)**. Higher productive tillers (446/m^2) and grains/panicle (168) were obtained with bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* bispyribac-sodium at 25 g/ha on 20 DAT, which were comparable with weeding with cono-weeder at 10, 20, 30 and 40 DAT. Increased yield attributes under these treatments might be due to effective and prolonged control of weeds, that led to increased nutrient uptake of rice with more sink capacity. Similar results of higher yield attributes by post-emergence application of bispyribac-sodium at 40 g/ha was reported by Nalini *et al.* (2012). Un-weeded control resulted in reduced yield parameters due to severe crop weed competition coupled with reduced uptake of nutrients by crop and increased uptake of nutrients by weeds. Panicle length and 1000-grain weight was not significantly influenced by different weed management practices.

Table 1. Effect of weed management practices on total weed density, total weed dry weight and weed control efficiency in SRI

Treatment	Total weed density (no./m^2)			Total weed dry weight (g/m^2)			Weed control efficiency (%)		
	30 DAT	45 DAT	60 DAT	30 DAT	45 DAT	60 DAT	30 DAT	45 DAT	60 DAT
Weeding with CW at 10, 20 and 30 DAT	3.44 (11.3)	5.22 (26.8)	5.59 (30.8)	1.85 (2.94)	2.22 (4.43)	3.19 (9.66)	75.6	73.6	69.8
Weeding with CW at 10, 20, 30 and 40 DAT	3.00 (8.5)	3.27 (10.2)	4.07 (16.1)	1.65 (2.21)	1.82 (2.80)	2.38 (5.15)	81.6	83.3	84.0
Bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* weeding with CW on 20 and 30 DAT	3.35 (10.7)	3.35 (10.7)	4.22 (17.3)	1.81 (2.78)	2.03 (3.63)	2.46 (5.54)	76.9	78.4	82.8
Weeding with PORW at 10, 20 and 30 DAT	4.22 (17.3)	6.88 (46.8)	7.86 (61.3)	2.21 (4.37)	3.17 (9.56)	4.49 (19.62)	63.6	43.1	38.9
Weeding with PORW at 10, 20, 30 and 40 DAT	4.16 (16.8)	5.71 (32.1)	6.86 (46.6)	2.24 (4.50)	2.87 (7.72)	3.86 (14.41)	62.6	54.0	53.5
Bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT*fb* weeding with PORW on 20 and 30 DAT	3.62 (12.6)	4.79 (22.4)	4.62 (20.8)	1.94 (3.28)	2.10 (3.91)	2.68 (6.66)	72.7	76.7	79.3
Bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* EPOE bispyribac-sodium at 25 g/ha on 20 DAT	2.66 (6.6)	3.05 (8.8)	3.85 (14.3)	1.49 (1.72)	1.69 (2.35)	2.25 (4.58)	85.7	86.0	85.7
Un-weeded control	6.83 (46.2)	9.04 (81.3)	10.43 (108.3)	3.54 (12.01)	4.16 (16.82)	6.29 (39.10)	-	-	-
LSD (p=0.05)	0.31	0.42	0.48	0.18	0.22	0.29	-	-	-

Figures in parentheses are original values; CW Cono-weeder; PORW - Power operated rotary weeder; DAT – Days after transplanting

Table 2. Effect of weed management practices on yield attributes, yield and economics of rice under SRI

Treatment	Yield attributes				Yield		Economics	
	Productive tillers (no./m^2)	Grains (no./ panicle)	Panicle length (cm)	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Net returns (x10^3 `/ha)	BCR
Weeding with CW at 10,20 and 30 DAT	380	147	25.2	25.0	4.66	6.70	39.40	2.07
Weeding with CW at 10,20,30 and 40 DAT	445	163	25.7	26.1	5.50	7.91	52.71	2.41
Bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* weeding with CW on 20 and 30 DAT	438	162	25.5	25.9	5.43	7.79	51.01	2.35
Weeding with PORW at 10, 20 and 30 DAT	338	130	25.0	24.7	4.05	5.76	29.92	1.82
Weeding with PORW at 10, 20, 30 and40 DAT	314	135	25.0	24.8	4.26	6.18	32.42	1.84
Bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* weeding with PORW on 20 and 30 DAT	402	140	25.3	25.6	4.74	6.96	39.42	2.03
Bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* EPOE bispyribac-sodium at 25 g/ha on 20 DAT	466	168	25.9	26.1	5.73	8.36	55.44	2.44
Un-weeded control	228	116	24.3	24.6	2.83	4.26	11.82	1.34
LSD (p=0.05)	36	16	NS	NS	0.48	0.57	-	-

CW – Cono- weeder; PORW - Power operated rotary weeder; DAT - Days after transplanting; BCR: benefit-cost ratio

The highest grain and straw yields of 5.72 and 8.36 t/ha, respectively were recorded by pre-emergence applicationof bensulfuron-methyl at 60 g/ ha + pretilachlor at 600 g/ha on 3 DAT *fb* early post-emergence application of bispyribac-sodium at 25 g/ ha on 20 DAT (**Table 2**). This was comparable with cono-weeding at 10, 20, 30 and 40 DAT and pre-emergence application of bensulfuron-methyl at 60 g/ ha + pretilachlor at 600 g/ha on 3 DAT *fb* weeding with cono-weeder at 20 and 30 DAT. This might be due to the cumulative effect of lesser weed density as well as dry weight, higher WCE and lesser nutrient removal by weeds as a result of reduced crop weed competition. This is in line with the findings of Yadav *et al.* (2009) and Veeraputhiran and Balasubramanian (2012).

Economic analysis

Application of bensulfuron-methyl 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* bispyribac-sodium at 25 g/ha on 20 DAT gave maximum net returns and BCR (`55436/ha and 2.44) due to increased grain and straw yields, which clearly showed the influence of weed free environment for crop growth and development (**Table 2**). These results were in line with the findings of Veeraputhiran and Balasubramanian (2012). Un-weeded control gave the lowest net returns and BCR as ` 11824/ha and 1.34, respectively) due to drastic reduction in grain yield by virtue of uncontrolled weed growth throughout the crop period. This was in conformity with the findings of Mirza *et al.* (2009).

It was concluded that pre-emergence application of bensulfuron-methyl at 60 g/ha + pretilachlor at 600 g/ha on 3 DAT *fb* early post-emergence application of bispyribac-sodium at 25 g/ ha on 20 DAT is an ideal weed management option for increased productivity and profitability of rice in SRI.

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Weed management in organically grown scented rice

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ABSTRACT

A field experiment on evaluation of weed management practices in scented rice under organic production system was conducted during 2017-18 at All India Coordinated Research Project on Farming System, College of Agriculture, Rewa (M.P.). *Fimbristylis dichotoma* was the most dominating weed in rice field followed by *Jussia suffurusticosa.* Incorporation of mustard oil cake at 5 t/ha along with one hand weeding gave maximum weed control efficiency (68%). Growth and development of rice was better with incorporation of mustard oil cake 15 days before sowing 5 t/ha + 1 hand weeding (HW) followed by two HW at 20 and 40 days after transplanting (DAT) and locally available weed mulch *Saccharum spontaneam* at 3 t/ha + 1 hand weeding . These treatments gave 34 to 56% higher grain yield as compared to farmer's practice of weed control as mulching with mango leaves. Net profit of ` 62061/ha was maximum in mulching with locally available weeds + 1 hand weeding followed by ` 56695/ha in two HW at 20 and 40 DAT.

Rice is an important crop of rice-wheat crop zone of Madhya Pradesh, which occupies an area of 1.93 million hectares with an average production of 2.78 million tonnes (Anonymous 2017). The average productivity of rice is 1.44 t/ha, which is low due to use of local varieties, weed competition, erratic and uneven distribution of monsoon rain with frequent prolonged dry period. Organic farming is a production system that avoids the use of synthetic chemical fertilizer, pesticides and growth regulating hormones and raises the rice with the use of organic manures, bio-fertilizers, oil cake, crop rotation, legumes, green manure and biological pest control.

Weeds become most limiting factor in organic farming. None of the cultural practices were found effective to reduce the weeds in rice under organic production system and grain yield of rice is reduced by 57 to 61% due to weed competition (Mukherjee *et al.* 2008). Some cultural practices like intercropping of *Sesbania* in rice, close row spacing or high seed rate, stale seed bed, mulching by crop residues or tree leaves, hand weeding and hoeing are found effective to reduce the weeds under organic rice production system. Any practices aimed at enhancing competitive availability of the crop and weed can bring down the adverse effect of weeds on rice crop (Rao *et al.* 2007). Seedling vigor, early growth rate, tillering ability, stale seed bed, higher fertilizer dose, hoeing and mulching can give competitive advantage to the crop.

Use of mustard oil cake is found beneficial as it increases the growth of rice and suppresses the weed growth (Islam *et al.* 2007). Intercropping suppress weeds better than sole cropping and thus provides an opportunity to utilize crop themselves as tools for weed management (Rao and Shetty 1981). Cultivation of rice at narrow/close row spacing has been found effective to reduce the weed growth and increase the rice yield as compared to wider row spaced rice crop (Bhan 1968). It has been reported by Bond and Grundy (2001) that organic farming is gaining momentum in India owing to the concerns expressed on the safety of environment, soil, water and food chain. Cultivating crops organically and at the same time maintaining higher production level is a big challenge. Since chemical intervention is not permitted for weed management, non-chemical weed management is the major limitation in rice under organic farming. Hence, the present study was conducted to identify suitable weed management method in organically grown scented rice.

The present investigation was conducted on silty clay loam soil of All India Coordinated Research Project on Farming System, Kuthulia Farm JNKVV, College of Agriculture, Rewa during *Kharif* season of 2017. The experimental field was low in available nitrogen (180.31 kg/ha), medium in available phosphorus (16.93 kg/ha) and high in available potash (283.6 kg/ha).

The scented rice variety '*PS-5*' was transplanted on 8th July 2017 using 22 days old seedlings. Two seedlings per hill were transplanted at the planting geometry of 20 x 15 cm in all the plots and i at spacing was kept 15 x 15 cm. The weed control treatments were two hand weedings (HW) at 20 and 40 days after transplanting (DAT), cono-weeder 20 DAT + one HW at 40 DAT, inter cropping with *Sesbania*, stale seed bed + reduced spacing up to 25% + mulching with wheat straw + one hand weeding, locally available weed mulch + 1 hand weeding, incorporation of mustard oil cake at 5 t/ha, 15 days before sowing + 1 HW and mulching with locally available tree dry leaves (mango) at 3 t/ha practiced by farmers as mulching under organic production system. The experimental design was RBD with three replications. The cropping system was rice-garlic. Fertilizer dose was kept 120 kg N/ha through 1/3rd N through FYM, 1/3rd N through vermicompost and 1/3rd N through oil cake.

Ten weed species were recorded in the experimental field (**Table 1**). The dominant weeds were *Fimbristylis dichotoma* (30.5%), *Jussia suffrusticosa* (20.3%), *Monochoria vaginalis* (15.9%), *Eclipta alba* (14.5%), *Polygonum barbatum* (8.7%), *Alternanthera sessilis* (5.7%) and *Echinocloa colona* (4.3%). The total monocot weeds were 50.7% while dicot weeds were 49.2%.

Fimbristylis dichotoma was dominating weed in hoeing through cono-weeder at 20 DAT and one HW at 40 DAT (**Table 1**). *Alternanthera sessilis* was dominating weed in stale seed bed + reduced spacing up to 25% + mulching with wheat straw + one hand weeding treatment. *Monochoria vaginalis* was dominating weed in mulching through locally available weed + 1 hand weeding, incorporation of mustard oil cake at 5 t/ha at 15 days before sowing + 1 HW and two hand weeding at 20 and 40 DAT. Among various cultural and mechanical treatments, two hand weeding at 20 and 40 DAT was found most effective method of weed control as compared to one hand weeding and mechanical hoeing. It was due to effective elimination of early and late emerging weeds by hand weeding. Hoieng with cono-weeder and hand weeding was found less effective as compared to two hand weedings because hoeing could control the weed between the rows, but the weeds within the rows were unaffected. Similar findings were also noted by Jain *et al.* (1988) and Ramamoorthy *et al.* (2009).

Inter cropping of *Sesbania* with rice reduced the *Echinocloa colona* and *Monochoria vaginalis* as compared to two hand weeding at 20 and 40 DAT due to faster growth and allelopathic effect of *Sesbania*. Inter cropping of *Sesbania* in rice reduced the weed intensity was also reported by Yadav *et al.* (2010). Stale seed bed delayed the planting of rice by 5 to 6 days and reduced row to row spacing reduced the problem of *Eclipta alba* and *Polygonum barbatum* as compared to two hand weeding given at 20 and 40 DAT. Similar findings were also reported by Bhan *et*

Table 1. Average weed biomass/m^2 at 40 DAT under various treatments

Treatment	*Echinocloa colonum*	*Monochoria vaginalis*	*Fimbristylis dichotoma*	*Jussia Suffrusticosa*	*Eclipta alba*	*Polygonum barbatum*	*Alternanthera sessillis*	Weed biomass (g/m^2) at harvest	Weed control efficiency (%)
Two hand weeding (20 and 40 DAT)	3.66 (2.03)	9.00 (3.08)	9.33 (3.13)	2.20 (1.64)	5.00 (2.34)	0.66 (1.08)	0 (0.70)	45.66	52.26
Conoweeder (20 DAT) + one HW (40 DAT)	3.66 (2.03)	7.66 (2.85)	8.66 (3.02)	1.90 (1.54)	4.33 (2.19)	1.16 (1.28)	4.66 (2.27)	55.00	42.50
Inter cropping with *Sesbania*	2.33 (1.68)	5.66 (2.41)	8.33 (2.97)	4.20 (2.16)	4.33 (2.19)	4.00 (2.12)	1.00 (1.22)	64.66	32.40
Stale seed bed + reduced spacing up to (25%) + mulching with wheat straw + one hand weeding	2.66 (1.77)	5.33 (2.41)	3.66 (2.04)	4.90 (2.32)	1.33 (1.35)	0 (0.70)	7.33 (2.79)	81.00	15.32
Locally available weed mulch + 1 hand weeding	2.33 (1.68)	7.33 (2.79)	4.33 (2.19)	2.30 (1.67)	2.33 (1.68)	0 (0.70)	3.66 (2.04)	69.33	27.52
Incorporation of mustard oil cake 15 days before sowing at 5 t/ha +1 HW	2.33 (1.68)	7.66 (2.85)	4.33 (2.19)	2.13 (1.62)	3.66 (2.03)	3.66 (2.03)	4.66 (2.27)	30.66	67.94
ITK practices by farmers as mulching with mango leaaves 3 t/ha	1.00 (1.22)	3.66 (2.04)	7.00 (2.73)	4.66 (2.27)	3.33 (1.95)	2.00 (1.58)	1.30 (1.34)	95.66	00.00
LSD (p=0.05)	0.02	0.04	0.01	0.02	0.02	0.03	0.08	15.2	-

Values in parentheses are the square root transformed value *al.* (1968), Ramamoorthy *et al.* (2009) and Singh (2014). Mulching through mango leaf at 3 t/ha for weed control as practiced by farmers and wheat straw mulching after stale seed bed + reduced spacing up to 25% + one hand weeding were found effective to reduced the weed intensity of *E. colona* and *M. vaginalis* as compared to two hand weeding at 20 and 40 DAT. Incorporation of oil cake at 5 t/ha in addition to organic manures and 1 HW at 20 DAT reduced the problem of *F. Dichotoma* and *M. Vaginalis,* which might be due to good rice growth owing to higher level of oil cake, which suppressed the weed growth. Similar finding was also reported by Islam *et al.* (2007).

Weed biomass was minimum (30.66 g/m^2) with incorporation of mustard oil cake at 5 t/ha (15 days before sowing) + 1 HW while it was maximum in mulching with mango leaves as farmers practice (95.66 g/m^2). Among weed control and cultural practices, hoeing through cono-weederat 20 DT + 1 HW at 40 DAT gave lowest weed biomass (45.66 g/m^2) followed by two hand weeding at 20 and 40 DAT. Weed control efficiency was maximum (67.94%) with incorporation of mustard oil cake at 5 t/ha (15 days before sowing) + 1 HW followed by hoeing through cono-weeder at 20 DAT + 1 HW at 40 DAT (52.26%). These treatments were found effective over hand weeding and mulching with mango leaves for weed control as farmer practice.

The plant height of rice was maximum in mulching with mango leaves for weed control followed by incorporation of mustard oil cake at 5 t/ha (15 days before sowing) + 1 HW (**Table 2**). The superior growth and yield attributes of rice due to incorporation oil cake has also been reported by Islam *et al.* (2007).

The productive tillers/meter row length and panicle length of rice were maximum in stale seed bed + reduced spacing up to 25% + mulching with wheat straw + one hand weeding at 40 DAT followed by incorporation of mustard oil cake at 5 t/ha (15 days before sowing) + 1 HW and two hand weedings at 20 and 40 DAT (**Table 2**). These treatments gave 7.75 to 17.58% higher number of productive tillers than farmers practice as mulching with mango leaves. Panicle were 8.23% longer under incorporation of mustard oil cake at 5 t/ha (15 days before sowing) + 1 HW followed by two hand weedings given at 20 and 40 DAT and in hoeing with cono-weeder at 20 DAT + 1 HW at 40 DAT.

Number of filled grains/panicle and test weight of rice were significantly maximum under incorporation of mustard oil cake at 5 t/ha (15 days before sowing) + 1 HW followed by locally available weed mulch + 1 hand pulling/hand weeding at 40 DAT. Test weight of rice was maximum (28.43g) in inter cropping with *Sesbania* followed by 27.53g in two hand weedings at 20 and 40 DAT. It may be due to weed free atmosphere to rice by two hand weedings at 20 and 40 DAT. The positive effect of two hand weedings on rice was also reported by Ramamoorthy *et al.* (2009) while Islam *et al.* (2007) reported the positive effect of extra oil cake given in rice.

Table 2. Rice growth and yield attributing characters, grain yield, straw yield, weed index and economics as affected by different weed control treatments

Treatment	Plant height (cm)	No. of productive tillers/m row length	Panicle length (cm)	No. of sound grains/ panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Weed index	Net profit (x10^3 `/ha)	B:C ratio
Two hand weedings (20 and 40 DAT)	75.2	69.7 (8.1%)	25.2	188.6 (31.1%)	27.5 (1.5%)	4.7 (33.7%)	10.09 (18.3%)	00	56.96 (82.2%)	2.16 (25.6%)
Conoweeder 20 DAT + one HW (40 DAT)	79.1	64.5 (0.2%)	25.3	141.2 (0)	27.3 (0.5%)	4.2 (19.4%)	10.43 (22.3%)	10.7	50.67 (62.0%)	2.05 (19.2%)
Inter cropping with *Sesbania*	74.9	66.0 (2.4%)	25.0	143.6 (0)	28.4 (4.8%)	3.8 (7.7%)	9.67 (13.4%)	19.4	48.77 (56.0%)	2.18 (26.7%)
Staleseedbed + reducedspacing up to (25%) + mulchingwithwheatstraw + one hand weeding	73.9	75.8 (17.6%)	24.2	145.0 (0.8%)	27.4 (1.0%)	4.2 (20.8%)	8.62 (1.0%)	9.6	48.32 (54.6%)	1.97 (14.5%)
Locally avalable weed mulch + 1 hand pulling/hand weeding	75.6	67.0 (3.9%)	24.3	154.5 (7.4%)	27.2 (0.1%)	4.7 (34.3%)	8.74 (2.5%)	-0.4	62.06 (98.5%)	2.38 (38.4%)
Incorporation of mustard oil cake 15 days before sowing at 5 t/ha + 1HW	87.4	69.4 (7.7%)	26.3	159.2 (10.6%)	27.3 (0.7%)	5.5 (56.3%)	12.74 (49.3%)	-16.9	4.43 (0)	1.03 (0)
ITK treatment on weed control practices by farmers as mulching with mango leaves	88.3	64.4 (0)	24.3	143.8 (0)	27.1 (0)	3.5 (0)	8.53 (0)	25.2	31.26 (0)	1.72 (0)
LSD (p=0.05)	1.00	2.44	0.44	6.43	0.14	9.28	5.19	-	-	-

Figures in parentheses are per cent increased over ITK treatment

The grain yield of rice was maximum (5.47 t/ha) with incorporation of mustard oil cake at 5 t/ha (15 days before sowing) + 1 HW, which was 56.3% higher than ITK (mulching with locally available tree dry leaves) treatment on weed control practiced by farmers as mulching with leaf of mango followed by 4.7 t/ha in locally available weed mulch + 1 hand pulling/hand weeding at 40 DAT and 4.68 t/ha in two hand weedings at 20 and 40 DAT.

Weed index was maximum (25.2%) with farmers practices of mulching with mango leaves for weed control followed by inter cropping with *Sesbania* and hoeing with cono-weeder at 20 DAT + 1 HW at 40 DAT. The similar finding was also reported by Islam *et al.* (2007).

It was concluded that incorporation of mustard oil cake at 5 t/ha 15 days before sowing along with 1 HW gave maximum weed control efficiency, greater yield attributing character of rice and maximum grain yield followed by two hand weedings at 20 and 40 DAT. These treatments gave 33 to 46% higher grain yield as compared to farmers practice of weed control as mulching with mango leaves at 3 t/ha. Net profit ` 62061/ha was maximum in mulching with locally available weed mulch *Saccharum spontaneum* at 3 t/ha + 1 hand pulling/hand weeding followed by ` 56695/ha in two hand weedings at 20 and 40 DAT.

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Comparative efficacy of herbicides against rock bulrush *Schoenoplectus juncoides* (Roxb.) Palla in wet-seeded rice

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ABSTRACT

Field experiment was conducted at the College of Agriculture, Vellayani during 2017- 2018 to assess the efficacies of pre-emergence, early post-emergence and post-emergence herbicides for managing rock bulrush *Schoenoplectus juncoides* (Roxb.) Palla, an emerging sedge weed in the lowland paddy fields of Kerala. A pre-emergence spray of bensulfuron-methyl + pretilachlor 60+ 600 g/ha at 4-7 days after sowing (DAS) was effective till 30 DAS with 93.3% reduction in weed count. At 45 and 60 DAS, lower weed density (2.09 and 3.15 no./m^2, respectively) and weed dry weight (0.13 and 1.83 g/m^2, respectively) were recorded for ethoxysulfuron 15 g/ha at 15 DAS *fb* HW at 40 DAS. Higher weed control efficiencies of 99.8% and 98.1% were obtained in plots treated with ethoxysulfuron 15 g/ha at 15 DAS *fb* HW at 40 DAS during critical stages of crop-weed competition (45 and 30DAS). Penoxsulam 22.5 g/ha at 15 DAS and ethoxysulfuron 15 g/ha at 15 DAS both *fb* HW at 40 DAS were on a par at 45 and 60 DAS in terms of weed control efficiency (99.1% and 97.9%, respectively. The weed removal of N, P and K (8.61, 3.13 and 10.95 kg/ha, respectively) were also lower with ethoxysulfuron 15 g/ha at 15 DAS *fb* HW at 40 DAS. The study revealed that rock bulrush could be effectively controlled by ethoxysulfuron 15 g/ha or penoxsulam 22.5 g/ha both at 15 DAS *fb* HW at 40 DAS.

Wet seeded rice is infested with a composite weed flora comprising of grasses, sedges and broad-leaved weeds. Among the three weed groups, sedges pose a greater threat to rice (Satapathy *et al*. 2017) as they are usually perennial with underlying propagules that help in tiding over unfavourable climatic conditions. Rock bulrush *Schoenoplectus juncoides* (Roxb.) Palla, a sedge weed belonging to Cyperaceae, problematic in the Asian countries has recently invaded the paddy fields of Kerala. *Schoenoplectus juncoides* has been documented to occur globally in direct seeded lowland rice. IRRI (2017) included *S. juncoides* as one among the twelve most troublesome weeds in the rice fields of South and South-East Asia. Rock bulrush, annual / perennial sedge with hollow stem was found to grow copiously in the lowland paddy field, field bunds, and associated water channels. The weed was observed to grow to a height of 66.76 cm at maturity, vigorously tillering with an average tiller production of 19.6 tillers/plant and fibrous roots growing to a mean depth of 17.76 cm with a dry weight of 0.99 g/plant and average biomass production of 0.96 t/ha (Umkhulzum 2018).

Uncontrolled weeds reduce the grain yield by 61% in wet-direct seeded rice (Maity and Mukerjee 2008). Though manual weeding is the farmer's practice, it cannot be inculcated as an effective strategy for managing rock bulrush, especially in wet-seeded broadcasted paddy owing to the failure in removing the underground weed propagules. The use of herbicides can maintain the weed below its economic threshold limits, but continuous use of herbicides can induce resistance in weeds. Shultana *et al*. (2016) observed integrated use of pre-or post-emergence herbicides in conjunction with hand weeding as a better weed management strategy in wet- seeded rice. Use of new generation herbicides is an attractive option for weed management due to lower application rates and lower mammalian toxicity. In the present investigation, application of pre-emergence, early-post emergence and post-emergence herbicides followed by hand weeding, were tested for their effectiveness in controlling *S. juncoides* in wet- seeded rice.

A field experiment was conducted during *Rabi* season (November 2017 to March 2018) in the lowland paddy field of Nemom block (8.4°N, 77.08°E and 28m above mean sea level) of Thiruvananthapuram, Kerala. Soil in the experimental field was sandy clay loam in texture, strongly acidic (pH 5.4) with normal electrical conductivity (0.47 dS/m) high organic carbon (1.10%), low available nitrogen (275.97 kg/ha), high available phosphorus (39.20 kg/ha) and high available potassium (240 kg/ha). The experiment was laid out in randomized block design (RBD) with 8 treatments and replicated thrice. The treatments were: bensulfuron methyl + pretilachlor 60 + 600 g/ha at 4-7 days after sowing (DAS) followed by (*fb*) hand weeding (HW) at 40 DAS, penoxsulam 22.5 g/ha at 15 DAS *fb* HW at 40 DAS, ethoxysulfuron 15 g/ha at 15 DAS *fb* HW at 40 DAS, carfentrazone-ethyl 20 g/ha at 15 DAS *fb* HW at 40 DAS, metsulfuron- methyl+ chlorimuron-ethyl 4 g/ha at 20 DAS *fb* HW at 40 DAS, 2,4-D sodium salt 1 kg/ha at 20 DAS *fb* HW 40 DAS, HW twice at 20 and 40 DAS and weedy check. Pre-germinated seeds of rice variety '*Sreyas*' (MO-22) was broadcasted onto the puddled soil. FYM 5 t/ha and fertilizer schedule for medium duration rice (90:45:45 kg N:P_2O_5:K_2O/ha) was adopted as per package of practices recommendation of KAU (2016). Weeds falling within the frame of 50 x 50 cm iron quadrant were collected at 15, 30, 45 and 60 DAS; counted and oven dried at 70 ± 5°C to a constant weight for taking the relevant observations on weeds. At maturity stage, weeds were uprooted and dried for nutrient analysis. Data requiring transformation were appropriately transformed and subjected to analysis of variance (ANOVA) applicable to randomized block design and the least significant difference (LSD) values at 5% level of significance were calculated to test significant difference between treatment means.

Weed flora

The weed spectra of the experimental field were associated with a multitude of weeds including grasses, sedges and broad-leaved weeds (BLW) with a clear dominance of sedges during the growing season (**Table 1**). At all stages of crop growth, rock bulrush (*S. juncoides*) co-occurred with the crop and dominated the field. *Fimbristylis miliacea*, *Isachne miliacea*, *Lindernia rotundifolia*, and *Ludwigia perennis* were also observed to infest the field throughout the crop life cycle. Broad-leaved weeds (BLW) were present at varying densities in the field, but did not dominate at any stage of the crop. The applied treatments were found to be effective in managing sedges and BLW during the cropping season, leaving behind grasses such as *Isachne miliacea* and *Digitaria sanguinalis*.

Effect on weed density

At 15 DAS, the density of *S. juncoides* was the lowest (0.67/m^2) in bensulfuron-methyl + pretilachlor 60 + 600 g/ha at 4-7 DAS with a reduction in weed count to the tune of 98.4% over weedy check which could be attributed to its pre-emergence spray at 4th day after wet-seeding. All other plots recorded higher densities of rock bulrush at 15 DAS due to the absence of any treatment application at that period of observation (**Table 2**). Effect of the pre-emergence spray of bensulfuron-methyl + pretilachlor 60 + 600 g/ha at 4-7 DAS lasted upto 30 DAS as evident from the reduction in weed density to 93.3%. Application of early post-emergence (15 DAS) and post-emergence herbicides (20 DAS) resulted in lower densities of rock bulrush at 30 DAS compared to weedy check. At the critical stages of the crop-weed competition in wet seeded rice (45 and 60 DAS) ethoxysulfuron 15 g/ha at 15 DAS *fb* HW at 35-40 DAS gave a considerable reduction in weed density. Son and Rutto (2002) observed ethoxysulfuron as an effective early post-emergence herbicide against

Table 1. Weed flora and relative density of weeds in the experimental field

Family	Scientific name	Common name	Relative density
Poaceae	*Isachne miliacea*	Blood grass	20.00
Poaceae	*Digitaria sanguinalis*	Crab grass	0.25
Cyperaceae	*Schoenoplectus juncoides*	Rock bulrush	72.00
	Fimbristylis miliacea	Globe finger rush	12.00
	Cyperus exaltatus	Tall flat sedge	1.00
	Cyperus haspan	Haspan flat sedge	0.25
	Cyperus difformis	Umbrella sedge	1.00
	Cyperus iria	Rice flat sedge	2.00
	Cyperus cyperoides	Pacific island flat sedge	0.25
Limnocharitaceae	*Limnocharis flava*	Water cabbage	3.00
Onagraceae	*Ludwigia perennis*	Water primrose	0.25
Scrophulariaceae	*Lindernia rotundifolia*	False pimpernel	2.00

Table 2. Effect of weed management practices on density of rock bulrush (no./m²) at 15, 30, 45 and 60 DAS

Treatment	15 DAS	30 DAS	45 DAS	60 DAS
Bensulfuron-methyl + pretilachlor 60+600 g/ha at 4-7 DAS *fb* HW at 40 DAS	0.67 (1.24)	3.58 (2.01)	6.81 (2.79)	10.49 (3.39)
Penoxsulam 22.5 g/ha at 15 DAS *fb* HW at 40 DAS	31.40 (5.69)	3.59 (2.14)	2.92 (1.97)	4.22 (2.28)
Ethoxysulfuron 15 g/ ha at 15 DAS *fb* HW at 40 DAS	34.22 (5.92)	5.96 (2.64)	2.09 (1.69)	3.15 (2.04)
Carfentrazone-ethyl 20 g/ha at 15 DAS *fb* HW at 40 DAS	22.55 (4.84)	4.04 (2.24)	5.04 (2.44)	7.43 (2.90)
Metsulfuron-methyl + chlorimuron ethyl 4 g/ha at 20 DAS *fb* HW at 40 DAS	32.33 (5.75)	6.78 (2.78)	7.21 (2.86)	9.34 (3.22)
2,4-D sodium salt 1 kg/ha at 20 DAS *fb* HW at 40 DAS	28.89 (5.43)	8.22 (3.04)	9.79 (3.28)	7.53 (2.92)
HW at 20 and 40 DAS	28.56 (5.24)	5.19 (2.47)	3.14 (2.03)	9.88 (3.29)
Weedy check	40.55 (6.46)	53.57 (7.39)	62.34 (7.96)	64.11 (8.07)
LSD(p=0.05)	1.450	0.640	0.550	0.270

The data were subjected to square root transformation ($\sqrt{x+0.5}$) and transformed values are given in parentheses

Table 3. Effect of weed management practices on weed dry weight (g/m²) at 15, 30, 45 and 60 DAS

Treatment	15 DAS	30 DAS	45 DAS	60 DAS
Bensulfuron-methyl + pretilachlor 60+600 g/ha at 4-7 DAS *fb* HW at 40 DAS	0.08 (1.04)	1.42 (1.51)	2.87 (1.97)	4.04 (2.25)
Penoxsulam 22.5 g/ha at 15 DAS *fb* HW at 40 DAS	10.62 (3.41)	1.58 (1.60)	0.66 (1.28)	1.99 (1.73)
Ethoxysulfuron 15 g/ha at 15 DAS *fb* HW at 40 DAS	13.17 (3.76)	1.56 (1.59)	0.13 (1.06)	1.83 (1.68)
Carfentrazone-ethyl 20 g/ha at 15 DAS *fb* HW at 40 DAS	11.79 (3.58)	1.25 (1.49)	1.59 (1.61)	4.03 (2.24)
Metsulfuron-methyl+ chlorimuron-ethyl 4 g/ha at 20 DAS *fb* HW at 40 DAS	11.99 (3.60)	2.38 (1.84)	2.80 (1.95)	6.33 (2.71)
2,4-D sodium salt 1 kg/ha at 20 DAS *fb* HW 40 DAS	12.94 (3.73)	2.26 (1.78)	1.85 (1.69)	3.55 (2.13)
HW at 20 and 40 DAS	11.98 (3.60)	1.76 (1.65)	0.80 (1.32)	2.78 (1.94)
Weedy check	14.11 (3.89)	35.47 (6.01)	70.11 (8.41)	96.05 (9.84)
LSD(p=0.05)	0.201	0.624	0.460	0.405

The data were subjected to square root transformation ($\sqrt{x+0.5}$) and transformed values are given in parentheses

sedges and BLW in cereals, especially rice. The duration of weed control got extended when the application of ethoxysulfuron 15 g/ha at 15 DAS was coupled with HW at 35-40 DAS. Hence the combination of the early post-emergence application of ethoxysulfuron and HW could give effective control of rock bulrush throughout the crop growing season. Ethoxysulfuron has been proved especially good for controlling the sedges belonging to *Scirpus* sp. (Sondhia and Dixit 2012).

Effect on weed dry weight

Bensulfuron- methyl + pretilachlor 60 + 600 g/ha at 4 DAS recorded lower dry weight of rock bulrush at 15 DAS due to lesser weed count in the plots treated (**Table 3**). In aerobic rice, Sunil *et al.* (2010) observed that the pre-emergence application of bensulfuron-methyl + pretilachlor 60 + 600 g/ha *fb* HW at 40 DAS was effective in reducing the weed count and dry weight. At 45 and 60 DAS, ethoxysulfuron *fb* HW recorded lower weed dry weights of 0.13 g/m² and 1.83 g/m² respectively. Weed dry weight recorded at 45 and 60 DAS in plots treated with ethoxysulfuron *fb* HW at 40 DAS were 83.8% and 34.2% lesser than the plots hand weeded twice at 20 and 40 DAS. This indicated that both ethoxysulfuron and penoxsulam *fb* HW were more effective in controlling rock bulrush than HW twice at a critical period of crop-weed competition (20 and 40 DAS). Singh *et al.* (2008) reported the ineffectiveness of HW due to weed escape and re-growth. The dry weight of rock bulrush in weedy check plots showed a steady progression from 15 to 60 DAS recording dry weights of 14.11, 35.47, 70.11 and 96.05 g/m². Higher weed dry weight indicated higher biomass production by weeds in the system.

Effect on weed control efficiency

All the herbicides were found to be equally effective in controlling rock bulrush till 30 DAS as evidenced by the higher WCE. However, at critical stages of the crop-weed competition, ethoxysulfuron *fb* HW provided higher weed control efficiencies of 99.8% and 98.1% respectively and was at par with penoxsulam 22.5 g/ha *fb* HW. The study proved the superiority of these 2 early post-emergent herbicides over HW twice for control of *Schoenoplectus juncoides*in wet-seeded rice (**Table 4**.). The study also revealed the superiority of bensulfuron methyl + pretilachlor 60 + 600 g/ha as pre-emergent spray for initial control of rock bulrush with a higher WCE. Arya and Ameena (2016) reported the superiority of pre-emergence application of bensulfuron-methyl + pretilachlor 60 + 600 g/ha in terms of WCE in semi-dry rice in comparison with HW twice.

Nutrient removal by weed

Analysis of N, P and K removal by the weed at maturity stage (60 DAS) recorded higher nutrient removal of 8.61, 3.13 and 10.95 kg NPK/ha in weedy check (**Table 5**) while, ethoxysulfuron 15 g/ha *fb* HW resulted in reduced weed dry weight and lower

Table 4. Weed control efficiencies (%) of herbicides at 15, 30, 45 and 60 DAS

Treatment	15 DAS	30 DAS	45 DAS	60 DAS
Bensulfuron-methyl + pretilachlor 60+600 g/ha at 4-7 DAS *fb* HW at 40 DAS	99.40 (10.02)	95.55 (9.82)	95.85 (9.84)	95.75 (9.84)
Penoxsulam 22.5 g/ha at 15 DAS *fb* HW at 40 DAS	24.68 (5.04)	95.31 (9.81)	99.07(10.00)	97.90 (9.94)
Ethoxysulfuron 15 g/ha at 15 DAS *fb* HW at 40 DAS	6.60 (2.68)	95.60 (9.83)	99.82(10.04)	98.07 (9.95)
Carfentrazone-ethyl 20 g/ha at 15 DAS *fb* HW at 40 DAS	16.37 (4.16)	96.08 (9.85)	97.69 (9.93)	95.74 (9.84)
Metsulfuron-methyl + chlorimuron-ethyl 4 g/ha at 20 DAS *fb* HW at 40 DAS	15.09 (3.89)	92.92 (9.69)	95.92 (9.85)	93.31 (9.71)
2,4-D sodium salt 1 kg/ha at 20 DAS *fb* HW at 40 DAS	8.38 (2.95)	94.45 (9.77)	97.34 (9.92)	96.27 (9.86)
HW at 20 and 40 DAS	15.11 (3.97)	94.66 (9.78)	98.91 (9.99)	97.08 (9.90)
Weedy check	0.00	0.00	0.00	0.00
LSD(p=0.05)	1.352	0.198	0.050	0.031

The data were subjected to square root transformation ($\sqrt{x+0.5}$) and transformed values are given in parentheses

Table 5. Nutrient removal (kg/ha) by rock bulrush in wet-seeded rice

Treatment	N	P	K
Bensulfuron-methyl + pretilachlor 60+600 g/ha at 4-7 DAS *fb* HW at 40 DAS	0.35	0.14	0.45
Penoxsulam 22.5 g/ha at 15 DAS *fb* HW at 40 DAS	0.17	0.07	0.22
Ethoxysulfuron 15 g/ha at 15 DAS *fb* HW at 40 DAS	0.16	0.07	0.20
Carfentrazone-ethyl 20 g/ha at 15 DAS *fb* HW at 40 DAS	0.34	0.14	0.44
Metsulfuron-methyl + chlorimuron-ethyl 4 g/ha at 20 DAS *fb* HW at 40 DAS	0.53	0.22	0.71
2,4-D sodium salt 1 kg/ha at 20 DAS *fb* HW at 40 DAS	0.30	0.12	0.40
HW at 20 and 40 DAS	0.24	0.10	0.31
Weedy check	8.61	3.13	10.95
LSD (p=0.05)	0.674	0.213	0.895

removal of 0.16, 0.07 and 0.20 kg NPK/ha respectively. Higher nutrient removal in the weedy check plot was in conformity with the findings of Parameswari and Srinivas (2014). Higher K removal by the weed was observed due to high K content of 1.14%. In direct-seeded rice, nutrient removal by the weeds was observed to be 34.8, 15.6 and 42.3 kg NPK/ha from un-weeded control as per the work of Singh *et al.* (2005). Higher NPK removal triggered growth and related attributes of weeds helping them to grow robust and competent.

It was concluded that in wet-seeded rice, early post-emergence application (at 15 DAS) of ethoxysulfuron 15 g/ha or penoxsulam 22.5 g/ha followed by one hand weeding at 40 DAS were effective for the management of *Schoenoplectus juncoides*.

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Bio-efficacy of carfentrazone-ethyl 40% DF against weeds in wheat and its carryover effect on succeeding sorghum

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ABSTRACT

Effects of different broad-leaf herbicides against complex weed flora in wheat and carryover effect on succeeding sorghum were evaluated at Agronomy Research Farm, CCS Haryana Agricultural University, Hisar during 2017-18. Application of different herbicides significantly reduced the dry weight of weeds compared to weedy check at different growth stages of crop. At 30 days after treatment (DAT), weed control efficiency (WCE) was higher with carfentrazone 20 g/ha (91.8%) compared to carfentrazone 10 g/ha (78.9%). Carfentrazone at different doses provide better control of weed as compared to 2,4-D amine at 60 DAT and at harvest. Number of tillers/m^2 (401) and grain yield (6.11 t/ha) were recorded significantly higher with carfentrazone at 20 g/ha than carfentrazone at 10 g/ha (372 and 5.62 t/ha), 2,4-D amine at 500 g/ha (366 and 5.26 t/ha) and metsulfuron at 4 g/ha (389 and 5.79 t/ha), respectively. Also, there were no residual effect different herbicides on succeeding sorghum.

Due to continuous use of clodinafop-propargyl and pinoxaden herbicides for the last 20 and 10 years, respectively, weed flora of wheat has now been shifted towards broad-leaf weeds. Sulfosulfuron recommended to control grassy weeds *Phalaris minor* and *Avena ludoviciana* provides marginal control of broad-leaf weeds. 2,4-D is not effective against certain weed species such as *Rumex dentatus, Malva parviflora, Convolvulus arvensis, Cirsium arvensis* and *Lathyrus aphaca*. Metsulfuron and 2,4-D are being widely used, but these herbicides do not provide any control of *C. arvensis, Solanum nigrum* and *Malva parviflora* for which carfentrazone is very effective (Punia *et al.* 2006, Walia and Singh 2006). Moreover, combination of 2,4-D with recommended herbicides like clodinafop and fenoxaprop results in antagonism. Secondly many wheat cultivars show malformed spikes due use of 2, 4-D (Balyan and Panwar 1997), Hence, there was strong need for a herbicide which can provide effective control of broad-leaf weeds in wheat. A contact, non-residual, translocated herbicide carfentrazone-ethyl of aryl triazolinone family have been found effective to control broad-leaf weeds in wheat (Singh *et al.* 2004) by inhibiting activity of protoporphyrinogen oxidase in chlorophyll biosynthetic pathway (Witkowski and Halling 1989) against broad-leaf weeds. Therefore, the present investigation was conducted during winter (*Rabi*) season of 2017-2018 and compared with existing brands of carfentrazone available in market.

The soil of the experimental field was sandy loam soil in texture with a pH of 8.2. Experiment was conducted in randomized design with three replications, keeping a plot size of 6.0 x 6.0 m. Wheat crop variety '*WH 1105*' was planted on 28th November, 2017 by using 100 kg seed /ha. Crop was raised as per package of practices recommended by CCS HAU, Hisar except herbicide treatments given as per treatment (details in tables 1-5). All the herbicides were applied at 35 days after sowing (DAS) by knapsack sprayer using 500 litres of water per ha.

Weed density was recorded before spray and at 30 and 60 days after treatment (DAT) and at harvest. Visual toxicity on crop was recorded at 1, 3, 5, 7, 10 DAT on a 0 -10 scale where 0 = No injury and 10 = Complete mortality of crop plant. At harvest, the numbers of ear bearing shoots were counted from two randomly marked spots per meter row length in each plot and converted into per square meter.

To study the residual carry over effect of different herbicides, sorghum crop was planted in the same layout without disturbing the original layout of the experiment. No. of plants per meter row length, plant height and green fodder yield of sorghum were recorded to study the residual effect of different treatments. Weather data on different parameters was recorded during October 2017-July, 2018.

Weed flora

Weed flora of experimental field in weedy check consisted of broad-leaf weeds, *viz. Rumex dentatus* (29.2%), *Convolvulus arvensis* (1.27%), *Anagallis arvensis* (32.85%), *Chenopodium album* (2.55%), *Lathyrus aphaca* (11.4%) *and Medicago denticulata* (22.8%).

Effect on weeds

All the herbicides significantly reduced the density and dry weight of weeds as compared to weedy check. 2,4-D amine applied at 500 g/ha was not effective against *C. arvensis*, *L. aphaca*, *A. arvensis* and *M. denticulata* whereas metsulfuron applied at 4 g/ha was not effective against *C. arvensis* and *L. aphaca* (**Table 1-3**). All the herbicide treatments caused significant reduction in dry weight of weeds as compared to weedy check at 30, 60 DAT and at harvest. At 30 DAT, minimum dry weight of weeds (2.13 g/m^2) was recorded with carfentrazone 20 g/ha (Bharat Rasyan) with WCE 91.8% which was at par with carfentrazone 40 g/ha but significantly higher than its lower dose 10 g/ha. At 60 DAT, minimum weed dry weight (3.36 g/m^2) was

Table 1. Effect of different weed control treatments on density of (no./m^2) two weeds in wheat

Treatment	Dose (g/ha)	Time of application	*Rumex dentatus*				*Convolvulus arvensis*			
			Before spray	30 DAT	60 DAT	At harvest	Before spray	30 DAT	60 DAT	At harvest
Carfentrazone	10	35 DAS	7.21(51.3)	2.08(4.0)	1.82(2.7)	1.82(2.7)	1.93(3.0)	1.41(1.0)	1.71(2.0)	1.47(1.3)
Carfentrazone	20	35 DAS	7.45(55.0)	1.24(0.7)	1.67(2.0)	1.55(1.7)	1.75(2.3)	1.0(0)	1.0(0)	1.41(1.3)
Carfentrazone	40	35 DAS	7.15(53.0)	1.24(0.7)	1.41(1.3)	1.14(0.3)	1.67(2.0)	1.0(0)	1.0(0)	1.33(1.0)
Carfentrazone (market sample)	20	35 DAS	7.54(56.3)	2.07(3.3)	1.0(0)	1.24(0.7)	1.82(2.3)	1.0(0)	1.0(0)	1.0(0)
2,4-D amine	500	35 DAS	7.35(53.3)	1.73(2.0)	1.0(0)	1.49(1.3)	2.10(3.7)	1.96(2.9)	1.82(2.3)	2.10(3.7)
Metsulfuron	4	35 DAS	7.30(54.7)	1.55(2.0)	1.0(0)	1.73(2.3)	1.79(2.3)	1.91(2.7)	1.73(2.0)	1.67(2.0)
Weedy check	-	-	7.35(53.0)	5.89(36.7)	3.10(8.7)	2.72(6.7)	1.79 (2.3)	1.79(2.3)	1.73(2.0)	2.25(4.0)
LSD (p=0.05)			NS	1.19	0.23	0.73	NS	0.48	0.33	0.48

***Transformed values $(\sqrt{x+1})$, original values are given in parentheses; DAT: Days after treatment

Table 2. Effect of different treatment on density of (no./m^2) of two weeds in wheat

Treatment	Dose (g/ha)	Time of application	*Anagallis arvensis*				*Chenopodium album*			
			Before spray	30 DAT	60 DAT	At harvest	Before spray	30 DAT	60 DAT	At harvest
Carfentrazone	10	35 DAS	8.08(55.3)	1.90(2.67)	1.24(0.6)	1.63(1.7)	2.46(5.33)	2.51(5.3)	2.36(4.7)	2.07(3.3)
Carfentrazone	20	35 DAS	7.60(63.7)	1.49(1.33)	1.41(1.3)	1.41(1.3)	2.57(5.67)	1.49(1.3)	1.0(0)	1.0(0)
Carfentrazone	40	35 DAS	8.34(62.7)	1.24(0.67)	1.0(0)	1.0(0)	2.45(5.33)	1.0(0)	1.0(0)	1.0(0)
Carfentrazone (market sample)	20	35 DAS	8.44(66.3)	1.24(0.67)	1.0(0)	1.0(0)	2.36(4.67)	1.49(1.3)	1.0(0)	1.0(0)
2,4-D amine	500	35 DAS	7.68(58.3)	4.79(22.0)	4.35(19.0)	4.24(17.0)	2.37(4.67)	1.86(2.7)	1.0(0)	1.0(0)
Metsulfuron	4	35 DAS	7.88(61.3)	1.48(1.67)	1.0(0)	1.0(0)	2.13(3.67)	1.47(1.3)	1.0(0)	1.0(0)
Weedy check	-	-	7.85(60.0)	5.80(32.67)	5.52(29.7)	5.16(25.7)	2.32(4.67)	2.36(4.7)	2.22(4.7)	2.23(4)
LSD (p=0.05)			NS	0.73	0.40	0.50	NS	0.59	0.45	0.48

***Transformed values $(\sqrt{x+1})$, original values are given in parentheses; DAT: Days after treatment

Table 3. Effect of different treatment of density on (no./m^2) two weeds in wheat

Treatment	Dose (g/ha)	Time of application	*Lathyrus aphaca*				*Medicago denticulata*			
			Before spray	30 DAT	60 DAT	At harvest	Before Spray	30 DAT	60 DAT	At harvest
Carfentrazone	10	35 DAS	4.16(16.7)	3.09(8.7)	2.32(4.7)	1.24(0.7)	6.39(40.7)	4.35(18.0)	4.27(17.3)	1.75(2.3)
Carfentrazone	20	35 DAS	4.25(19.3)	3.00(8.0)	1.49(1.3)	1.49(1.3)	6.94(49.7)	3.49(11.3)	2.51(5.3)	1.49(1.3)
Carfentrazone	40	35 DAS	3.96(15.3)	2.65(6.0)	1.55(2.0)	1.24(0.7)	7.24(52.0)	3.31(10.0)	2.95(8.0)	1.14(0.3)
Carfentrazone (market sample)	20	35 DAS	4.40(18.3)	2.88(4.7)	2.07(3.3)	2.45(5.0)	6.52(42.0)	4.18(16.7)	2.87(7.3)	1.49(1.3)
2,4-D amine	500	35 DAS	3.67(15.0)	4.04(15.3)	3.19(9.3)	2.99(0.7)	5.67(32.3)	4.28(17.3)	4.51(19.3)	1.0(0)
Metsulfuron	4	35 DAS	3.85(16.7)	4.09(16.0)	3.21(7.3)	2.88(7.3)	4.97(24.3)	3.31(10.7)	1.77(3.3)	1.0(0)
Weedy check	-	-	4.69(21.0)	4.35(18.0)	3.85(14.0)	3.85(14.0)	6.53(41.7)	6.24(38.0)	3.87(11.3)	3.95(14.7)
LSD (p=0.05)			NS	0.50	0.82	0.53	NS	0.70	0.82	0.52

*** Transformed values $(\sqrt{x+1})$, original values are given in parentheses; DAT: Days after treatment

Table 4. Effect of different treatment on weeds dry weight, number of tillers and grain yield of wheat

Treatment	Dose (g/ha)	Time of application	Dry weight of weeds (g/m²)			WCE (%)			No of tillers/m² (at harvest)	Grain yield (t/ha)
			30 DAT	60 DAT	At harvest	30 DAT	60 DAT	At harvest		
Carfentrazone	10	35 DAS	2.54(5.5)	2.91(7.5)	5.10(25.3)	78.9	78.7	62.8	372	5.62
Carfentrazone	20	35 DAS	1.75(2.1)	2.05(3.7)	2.92(7.5)	91.8	89.5	86.0	401	6.12
Carfentrazone	40	35 DAS	2.08(3.5)	2.04(3.4)	2.44(5.0)	86.1	90.4	92.6	402	6.21
Carfentrazone (market sample)	20	35 DAS	2.16(3.7)	2.23(4.0)	2.72(7.5)	86.0	88.7	89.0	399	6.14
2,4-D amine	500	35 DAS	2.47(5.2)	2.97(8.4)	6.80(45.3)	79.9	76.3	33.6	366	5.26
Metsulfuron	4	35 DAS	2.13(3.9)	2.17(3.8)	2.90(7.5)	85.2	89.3	89.0	389	5.79
Weedy check	-	-	5.21(26.2)	5.94(35.4)	8.20(68.3)	0	0	0	353	4.96
LSD (p=0.05)			1.41	0.77	1.74	-	-	-	21.3	0.13

*****Transformed values ($\sqrt{x+1}$), original values are given in parentheses; DAT: Days after treatment

recorded with carfentrazone 40 g/ha with WCE 90.4% but statistically at par with carfentrazone (Bharat Rasyan and market sample) and metsulfuron 4 g/ha. At harvest, all herbicides caused significant reduction in dry weight of weeds except 2,4-D amine which was at par with weedy check. Carfentrazone 20 g/ha did not show any phytotoxicity on wheat plants in terms of yellowing, stunting and necrosis, hyponasty and epinasty. Carfentrazone at 40 g/ha showed yellowing with intensity of 4 (0-10 scale) at 3 DAT which diminished with time and remained only 1 at 7 DAT. No stunting, necrosis, hyponasty and epinasty of wheat plants was observed with carfentrazone 40 g/ha and no any yield penalty.

Effect on yield

Different weed control treatments had a bearing on grain yield and yield attributing characters of wheat. Maximum number of tillers (402/m^2) were recorded with carfentrazone 40 g/ha which was at par with carfentrazone 20 g/ha (Bharat Rasyan and market sample) but higher than carfentrazone 10 g/ha, metsulfuron and 2,4-D amine (**Table 4**). Similar trend was observed with grain yield of wheat. Presence of weeds throughout growing season caused 20.1% reduction in grain yield of wheat. Brar *et al*. (2005) and Patel *et al*. (2005) also reported excellent efficacy of carfentrazone against broadleaf weeds in wheat.

Residual effect on succeeding crop

Carfentrazone at any dose did not show any residual effect on succeeding sorghum. Fodder yield in plots treated with carfentrazone 20 g/ha (Bharat Rasyan) was maximum 44.9 t/ha being at par with carfentrazone 20 g/ha (Market sample) and untreated check. Punia *et al*. (2006) did not report any residual carryover effect of carfentrazone on succeeding sorghum crop

Carfentrazone 40% DF supplied by Bharat Rasyan Ltd. at 20 g/ha applied at 35 DAS of wheat successfully controls broadleaf weeds in wheat without causing any residual toxicity on succeeding sorghum.

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Flauazifop-p-butyl against grasses in cotton and its residual effect on succeeding blackgram

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ABSTRACT

A field experiment was conducted during rainy seasons of 2010-11 and 2011-12 at Guntur, Andhra Pradesh, India to evaluate the bio-efficacy of fluazifop-p-butyl against grassy weeds in cotton and its residual effect on succeeding crop of blackgram during the winter season. Results revealed that among different doses of fluazifop-p-butyl, post-emergence application of fluazifop-p-butyl 167 g/ha reduced grassy weed growth and recorded higher crop dry weight, yield components and seed cotton yield (1915 kg/ha) over its lower doses (100 and134 g/ha) but was on par with the highest dose of 335 g/ha in both the years. None of the doses of fluazifop-p-butyl including the highest dose (335 g/ha) did not cause any injury to cotton. In a field experiment, residual carry over effect of fluazifop-p-butyl at different doses of 100 to 335 g/ha was studied using blackgram as a succeeding crop. Differences were non-significant on plant population, plant height, crop dry weight and seed yield of blackgram indicating that there was no residual effect of fluazifop-p-butyl in the soil after harvesting of the cotton crop. It was concluded that the post- emergence application of fluazifop-p- butyl 167 g/ha was effective in controlling grassy weeds in cotton without any crop injury and residual effect on succeeding crop.

Cotton being a wide row spaced and initial slow growth crop weeds effectively compete for the crop for nutrients, water etc. and reduce the yield to an extent of 74% depending upon type and intensity of weed flora (Rao *et al.* 2007, Madhu *et al.* 2014, Rao and Ratnam 2015). Further, during rainy season due to incessant rains, intercultivation is not possible which also results in severe weed competition. Due to shortage of labour and increased cost of labour wages, farmers are repeatedly asking for selective post-emergence herbicides. Though, information on selectivity of some of the herbicides like fenoxaprop-ethyl, quizalofop-ethyl, cyhalofop-butyl *etc.* is available (Rao 2011, Madhu *et al.* 2014 and Rao 2014) the information pertaining to bioefficacy of fluazifop-p-butyl (butyl 2-(4-{[5-(trifluoromethyl) pyridin-2-yl]oxy}phenoxy) propanoate) on cotton is scanty, particularly under local conditions of Andhra Pradesh, India. Keeping this in view, the present investigation was undertaken to evaluate the bio-efficacy of fluazifop-butyl at different doses against grassy weeds in comparison with presently recommended herbicides like pendimethalin and paraquat and its residual effect on succeeding blackgram crop

A field experiment was conducted consecutively for two years during rainy and winter seasons of 2010-11 and 2011-12 at Acharya N.G. Ranga Agricultural University, Regional Agricultural Research Station, Lam, Guntur, Andhra Pradesh, India. The soil of the experimental field was clay loam with a pH of 7.9, with low in available nitrogen (230 kg/ha) and phosphorus (10 kg/ha) and high in available potassium (350 kg/ha). The experiment consisting of eight treatments (fluazifop-p-butyl 100, 134, 167, 335 g/ha, paraquat 600 g/ha, pendimethalin 750 g/ha, hand weeding at 20, 40, 60 DAS along with weedy check) was laid out in a randomized block design with three applications. Cotton variety *Mallika Bt.* was sown by adopting a spacing of 90 x 60 cm during the 1st week of August 2010 (first year) and 1[st] week of July 2011 (second year). The crop survived mostly on the rainfall received during both the years (1084.1 mm in 48 rainy days during the first year and 568.8 mm in 38 rainy days during the second year). All the locally recommended package of practices except weed control was followed to raise the cotton crop. All the post- emergence herbicides were sprayed with knapsack sprayer fitted with a flat fan nozzle at 23 DAS as per schedule using a spray volume of 500 l/ha. Before spraying the post-emergence herbicides, all the sedges and broad-leaf weeds were removed, allowing only the grassy weeds to remain. The data on the density of grassy weed species and weed dry weight per unit area were recorded at 40 days after application (DAA) of herbicide and at final picking. The data on weed density and dry weight were subjected to square root transformation before statistical analysis to normalize their distribution (Panse and Sukhatme 1978). Economics of different treatments were calculated taking into prevailing market prices of inputs and output.

The residual effect of fluazifop-p-butyl at different doses was studied on the succeeding blackgram (cv. '*PU31*'). All the recommended package of practices except chemical weed control was followed to raise the blackgram crop. The crop was irrigated as and when needed. The data on blackgram population per unit area was recorded at 10 DAS. The yield attributes and yield were recorded at the time of maturity.

Effect on weeds

The experimental field was dominated by the natural infestation of *Echinochloa colona* (L.) Link, *Dinebra retroflexa* Jacq, *Panicum repens* L., *Dactyloctenium aegyptium* L., *Leptochloa chinensis* and *Cynodon dactylon* (L.) Pers., which consisted of more than 90% of the total weed population. Other weeds like *Phyllanthus niruri* L., *Digera arvensis Forsk*, *Cleome viscose* L., *Trianthema portulacastrum* L. were also present but their population was negligible and therefore removed before the herbicide spray.

The density and dry weight of grassy weeds were significantly reduced by all the fluazifop-p-butyl treatments compared to weedy check (**Table 1** and **2**) at both stages of observation. At 40 DAA, among the different doses, post-emergence application of fluazifop-p-butyl at 167 g/ha was found effective in reducing the density and dry weight of grasses with 67% weed control efficiency (WCE) and was found to be on par with its all other doses of fluazifop-p-butyl. Among the individual species, the density of *Echinochloa colonum* was effectively reduced (71%) followed by *Dactyloctenium aegyptium* (68%) and *Panicum repen*s (66%) at 40 DAA. Further, the highest WCE of 71% was observed with the highest dose of fluazifop-p-butyl (335 g/ha) and none of the treatments could reach to the level of the hand weeding at 15 and 30 DAS in reducing the weed growth which recorded the highest WCE of 82% at 40 DAA. An almost a similar trend was observed at final picking stage. The increased weed control in these treatments might be due to effective control of the grassy weeds during the critical period of crop growth.

Effect on cotton crop

Fluazifop-p-butyl at all doses (100 to 337 g/ha) did not cause any injury to cotton. Crop dry weight, yield components, and yield were significantly influenced by the different treatments under study over a weedy check (**Table 2**). Among the fluazifop-p-butyl treatments, post-emergence application of fluazifop-p-butyl at 167 g/ha recorded maximum crop dry weight, number of bolls per plant, boll weight and seed cotton yield (1915 kg/ha).This treatment was on par to its next lower (134 g/ha) and

Table 1. Density of different weed species as influenced by different treatments in cotton (pooled data)

Treatment	Dose (g/h)	Time of application (DAS)	*Echinochloa colonum* (no./m^2)		*Panicum repens* (no./m^2)		*Cynodon dactylon* (no./m^2)		*Leptochloa chinensis* (no./m^2)		*Dactyloctenium aegyptium* (no./m^2)		*Dinebra retroflexa* (no./m^2)	
			40 DAA	Final picking	40 DAA	Final picking	40 DAA	Final picking	40 DAA	Final picking	40 DAA	Final picking	40 DAA	Final picking
Weedy check	-	-	6.21 (34.50)	4.0 (16.85)	3.02 (9.18)	2.41 (5.5)	2.01 (4.33)	2.01 (4.83)	2.18 (4.68)	2.10 (4.0)	3.63 (13.68)	3.58 (12.67)	4.45 (19.82)	3.85 (15.67)
Fluazifop-p-butyl	100	23	3.26 (10.17)	1.89 (3.33)	1.9 (6.18)	1.43 (1.88)	0.97 (0.50)	1.12 (0.90)	0.94 (0.68)	0.97 (0.48)	1.59 (3.35)	1.91 3.30)	2.34 (5.34)	1.41 (1.85)
Fluazifop-p-butyl	134	23	2.47 (5.67)	2.2 (4.82)	1.48 (1.83)	1.05 (0.67)	0.88 (0.33)	1.03 (0.67)	0.80 (0.16)	0.97 (0.48)	1.61 (2.18)	1.60 (2.15)	1.78 (3.52)	1.31 (1.50)
Fluazifop-p-butyl	167	23	1.82 (2.83)	1.85 (3.32)	1.03 (0.65)	0.88 (0.32)	0.71 (0.00)	0.88 (0.33)	0.80 (0.16)	1.10 (0.83)	1.18 (1.0)	1.16 (1.15)	1.58 (2.52)	1.12 (1.50)
Fluazifop-p-butyl	335	23	1.23 (1.17)	1.83 (3.68)	0.94 (1.70)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.12 (1.17)	0.97 (0.50)	1.27 (1.50)	1.03 (0.82)	1.14 (1.00)
Paraquat	600	23	5.20 (26.68)	3.71 (13.82)	2.30 (5.18)	1.84 (3.02)	1.49 (1.82)	1.53 (0.82)	1.61 (2.67)	1.53 (2.15)	2.28 (5.00)	2.28 (4.85)	3.67 (13.17)	2.69 (7.17)
Pendimethalin	750	1	3.22 (10.15)	2.21 (4.17)	1.78 (3.05)	1.32 (1.35)	1.11 (0.85)	1.38 (1.48)	1.50 (2.00)	1.11 (0.82)	1.26 (1.30)	1.22 (1.17)	2.25 (5.00)	2.02 (3.85)
Hand weeding	-	20,40&60	1.54 (2.33)	1.52 (2.01)	1.36 (0.33)	0.80 (0.15)	1.03 (0.62)	1.11 (0.83)	1.16 (0.98)	1.08 (0.85)	1.09 (0.82)	1.29 (1.17)	1.37 (1.50)	1.51 (1.82)
LSD (P=0.05)	-	-	0.94	0.94	0.63	0.46	0.61	0.55	0.75	0.64	0.70	0.80	0.86	0.89

Data transformed to transformation. Figures in parenthesis are original values. DAA-days after application

Table 2. Effect of different treatments on weed growth, yield components and yield of cotton (pooled data)

Treatment	Dose (g/ha)	Time of application (DAS)	Weed dry weight (g/m^2)		Crop dry weight (g/m^2)		No. of bolls/ plant	Boll weight (g)	Seed cotton yield (t/ha)		
			40 DAA	Final picking	40 DAA	Final picking			2010-11	2011-12	Pooled
Weedy check	-	-	15.3(238.2)	13.6(195.9)	20.7	243.3	10.76	4.56	0.88	0.63	0.76
Fluazifop-butyl	100	23	6.8(51.1)	8.3(71.9)	49.8	320.7	17.40	4.97	1.44	0.98	1.21
Fluazifop-butyl	134	23	5.9(38.6)	7.2(52.2)	62.4	416.3	19.00	5.29	1.82	1.26	1.54
Fluazifop-butyl	167	23	5.1(31.1)	6.4(41.7)	68.3	447.3	24.80	5.39	2.31	1.51	1.91
Fluazifop-butyl	335	23	4.4(22.3)	5.2(29.2)	56.1	430.0	19.90	4.92	1.88	1.32	1.60
Paraquat	600	23	9.2(88.8)	10.7(116.7)	36.9	304.3	16.40	4.74	1.04	0.98	1.01
Pendimethalin	750	1	8.3(71.4)	8.2(73.3)	53.9	399.7	19.33	5.20	1.64	1.01	1.32
Hand weeding	-	20, 40 and 60	2.8(9.8)	5.9(35.5)	72.8	472.2	31.97	5.72	2.47	2.10	2.28
LSD (p=0.05)	-	-	2.1	2.7	15.0	90.7	5.65	0.96	0.44	0.29	0.38

In case of weed dry\weight data transformed to $\sqrt{x}+½$ transformations. Figures in parenthesis are original values. DAA-days after application

Table 3. Effect of different treatments on plant population, growth and yield of succeeding blackgram (pooled data)

Treatment	Dose (g/ha)	Time of application (DAS)	Plant population/ m length at 10 DAS	Plant height (cm) at harvest	Crop dry weight (g/m^2) at harvest	No. of branches/ plant	No. of pods/ plant	No. of Seeds/ pod	100 seed weight (g)	Seed yield (kg/ha)		
										2010-11	2011-12	Pooled
Weedy check	-	-	14.3	17.1	134.5	3.4	25.4	5.6	3.45	442	439	441
Fluazifop butyl	100	23	14.2	15.9	143.5	3.2	28.3	5.7	3.34	480	482	481
Fluazifop butyl	134	23	14.2	16.2	146.2	3.5	25.7	5.6	3.35	535	510	523
Fluazifop butyl	167	23	13.8	16.7	166.8	3.5	30.5	5.7	3.60	566	539	553
Fluazifop butyl	335	23	13.0	19.0	150.7	3.6	29.1	5.5	3.46	504	482	493
Paraquat	600	23	13.5	16.1	147.0	3.5	29.3	5.8	3.41	514	496	505
Pendimethalin	750	1	13.6	17.6	153.3	3.9	27.3	5.6	3.56	501	496	433
Hand weeding	-	20,40&60	14.3	16.8	155.8	3.9	25.5	5.6	3.68	503	553	528
LSD (p=0.05)	-	-	N S	NS	NS	NS	NS	NS	NS	NS	NS	NS

the highest dose (335 g/ha) of fluazifop-p-butyl and also with hand weeding at 15 and 30 DAS which recorded the highest seed yield (2.28 t/ha). The increased yield in these treatments might be due to effective control of weeds at critical period as evidenced by higher WCE, which favoured the increased crop growth and ultimately on yield components and yield. The uncontrolled weed growth during the crop season reduced the seed cotton yield to the extent of 74% corroborating with those reported by Rao and Ratnam (2015).

Residual effect on succeeding blackgram crop

Post-emergence application of fluazifop-p-butyl at different doses ranging from 100 to 335 g/ha had no adverse effect on plant population, plant height, yield components and yield of succeeding blackgram crop (**Table 3**). The blackgram yield in fluazifop-p-butyl treatments ranged from 481 to 553 kg/ha.

It was concluded that post-emergence application of fluazifop-p-butyl 167 g/ha was found to be effective in controlling grassy weeds with out any crop injury in cotton and residual effect on succeeding blackgram crop.

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Metribuzin dissipation pattern in soil and its residue in soil and chilli

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ABSTRACT

Field study was carried out to determine the dissipation of metribuzin and its residues in soil and chilli. Vermicompost (2 t/ha) was used as organic amendments to enhance the degradation. Metribuzin was applied at single and double the dose of 500 and 1000 g/ha. The chilli variety '*Krishna Jolokia*' was grown with a recommended practices. The recoveries obtained for untreated soil and chilli were in acceptable range of (80.6–85.7%) and (86.8–92.2%) of the metribuzin standards and spiked samples. The limit of detection (LOD) – 0.003 µg/g and the limit of quantification (LOQ) – 0.01µg/g in soil and chilli. The metribuzin residue level ranged 0.153 – 0.356 µg/g on the day of application of metribuzin and further degraded to 0.023 – 0.087 µg/g on the 21st day of application. However, the half-life of metribuzin was observed to be 7 and 10 days with single and double the dose of application of metribuzin. Metribuzin residues did not persisted in soil beyond 30 days after application and in fruits.

Assam is known worldwide for the genetic diversity and hotness of the varieties of chillies. Crop weed competition for the space, water and nutrient at the early stage of growth period is not desirable as it affects the crop growth, yield and the nutritional quality. At present, weed management through herbicides has become more popular as compared to manual weeding in view of labour shortage and higher cost involvement. Metribuzin (4-amino-6-tert-butyl-3-methylthio-1, 2, 4- triazine- 5- one), a triazine herbicide is photo system II inhibitor.It binds to a protein of the photosystem II complexthat disrupts the electron transport chain. It has been observed that foliar applied metribuzin is moderately absorbed into the plant. Metribuzin can be used as a pre and post-emergence herbicide. As pre-emergence herbicide, metribuzin efficacy is based on the presence of soil moisture for broad spectrum weed control. It is commonly used for management of broad-leaf and grassy weeds in vegetables like crops like potato, chilli and tomato *etc*. The availability of metribuzin for plant absorption is affected mostly by soil pH (James *et al*. 1976). Herbicides vary in their potential to persist in soil. Herbicides that can persist to the next season may injure succeeding crops and require close monitoring. Metribuzin persistence in the soil does not significantly affected by the straw mulch present on the soil surface (Philip and Edward 2017). Differences occur in the sensitivity and tolerance of crop varieties against herbicides, which are consequently significant for practical crop protection. Due to the soil properties like large surface area and porosity, metribuzin adsorption is more prominent in soil (Oren and Chefetz 2012). Soil physico - chemical properties have significant effect on metribuzin adsorption capacity in soil and plant system (Ara *et al*. 2013) .Hence the present study was conducted to know the residue accumulation and dissipation of metribuzin in fruit and soil of chilli.

A field trial was conducted at Instructional cum Research Farm, Assam Agricultural University, Jorhat during 2016-17. The Chilli variety "*Krishna Jolokia*" was grown in plots with 4 x 3 m in size with a spacing of 45 x 45 cm and was arranged in a randomized block design with four replications. The treatments comprised of metribuzin 500 g/ha, and metribuzin 2 x 500 g/ha as pre-emergence. The physico - chemical parameters of the soil was determined by following the procedures suggested by Piper, 1966; Jackson, 1973 and Subbiah and Asija, 1956. The soils of the experimental field was acidic (pH-4.8), sandy clay loam in texture and had CEC - 8.46 c mol (p$^+$)/kg, organic carbon - 0.68% , available N - 264.74, P_2O_5–20.68, K_2O–76.98 kg/ha, respectively. The climatic conditions of Jorhat, as a whole, were sub-tropical and humid having summer and cold winter. Normally, monsoon rain starts from the month of May - June and continues up to the month of September-October. The meteorological parameters have been

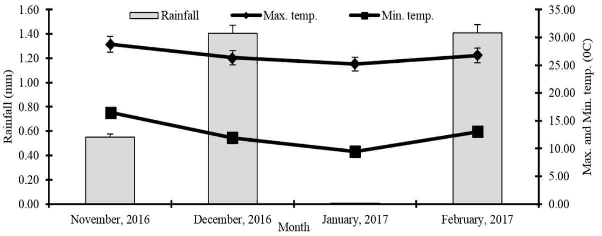

Figure 1. Maximum, minimum temperature, rainfall during metribuzin dissipation period in soil

presented in **Figure 1**. The recommended dose of fertilizer was120:60:60Kg/ha of N, P_2O_5 and K_2O respectively. The full doses of N,P and K and organic sources (vermincompost at 2 t/ha) was applied as basal.

Chemicals and reagents: Metribuzin was supplied by the company Sigma-Aldrich. Chloroform AR grade (e" 99.9%), methanol, dichloromethane and n – hexane were purchased from Merck Pvt. Ltd., Mumbai.

Preparation of the standard solutions: A stock solution of 1000 µg/g metribuzin was prepared by dissolving 100 mg of technical grade herbicide in 100 ml hexane. Further dilutions were made to make 100,10 and 1 µg/ ml hexane solution and internal standard solutions were stored at – 20^0 C in deep freeze until use. The reference standard of metribuzin was used for quantification, recovery and determination of retention time of metribuzin.

Sample collection and preparation: Representative composite surface soil (0-15 cm) and chilli samples were collected where no herbicides were applied for fortification study by feeding with known concentration of the metribuzin standards. Similarly, soil samples were collected periodically at 0,3,7,15,21 and 30 days from the day of metribuzin application (within 4 hours of herbicide application) as well as to thirty days after application. A part of soil and plant samples were collected after harvest of the chilli crop. Control as well as blank samples were maintained to check for the contamination and interferences. The soil samples were processed and stored in polythene bags for analysis of various physico–chemical parameters and herbicide residue by following standard protocols which directly or indirectly affects the factors like degradation, dissipation, adsorption and leaching of the metribuzin applied to field. The representative fruit (20 g) and soil (20 g) sample were weighed and blended separately and the samples were transferred to a shaking bottle and shaken on over end shaker after adding 60 ml of methanol: water 1:1 (v / v) for30 minutes. The resulting slurry was filtered through filter paper; the bottle was washed with additional 50 ml of methanol: water and the washings were filtered and left for 5 min.

Clean up and estimation: Partitioning and column clean-up was performed by transferring the combined extract and washing to separatory funnel. Methanol extract was partitioned with dichloromethane three times sequentially (3 x 20 mL) in presence of 30 ml of 2% aqueous sodium sulphate solution. The combined dichloromethane extracts were evaporated to dryness by using rotary evaporator, dissolved with 10 ml petroleum ether and subjected to chromatographic column determination. The column was pre washed with 4 ml petroleum ether: acetic ether 98:2 (v / v) which was discarded. Analytes were eluted with 5 ml petroleum ether: acetic ether 90: 10 (v / v). The eluate was evaporated to dryness in the rotary evaporator and the residues were re dissolved in 5 mln – hexane.

Instrument and operating conditions: The metribuzin residues were estimated by injecting samples to the Gas Chromatography with model No. GC–1000 and Series No. 2015/0505 having mega pore capillary column, 30 M, length x 0.25 mm, I.D. x 0.25micro metre, film thickness, Column – TG – 5MS GC column, Carrier gas – Nitrogen (> 99.999%), Flow rate – 40 mL/min, Detector – Electron Capture Detector (ECD) , Oven temperature - 210 ^{O}C injector Temperature - 240 ^{0}C – Detector temperature – 260 ^{0}C, Retention time - 3.09 min.

Injection volume : 0.5 µL

Determination of recovery: Recovery experiment was done for validation of the method described for the sample preparation. Untreated soil and fruit samples were fortified with known amounts of working standard solutions (0.01, 0.05, 0.1, 0.5 µg/ g) and processed according to the above procedures .Every recovery was done on five replications.

Method validation: Calibration curve for metribuzin was prepared by injecting different known concentrations (0.01, 0.05, 0.1, 0.5 and 1 µg/g) of the compound. A calibration curve have been plotted for the concentrations of the standards injected versus the peak area observed and the curve area was found to be linear up to the lowest concentration range of 0.01 µg/g.The approximate retention time was obtained at 3.1 minutes.

The regression equation and correlation coefficient (R^2) for metribuzin standard was as follows.

$$Y = 3255.07904 X + 296.42591. \quad R^2 - 0.98\ 99$$

The recoveries obtained for untreated soil and chilli were in acceptable range of (80.6 – 85.7%) and (86.8–92.2%) (**Table 1**) of the metribuzin standards and spiked samples.

Precision and detection and quantification limits: The limit of detection (LOD) – 0.003 µg/g in fortified soil and chilli. Based on signal to noise ratio **t**he limit of quantification (LOQ) for the method was defined as the lowest concentration of the compound in a sample

Table 1. Per cent recovery of metribuzin from fortified samples of soil and chilli

Sample spiked (mg/kg)	Percent recovery	
	Soil	Fruit
0.5	85.7	92.2
0.1	83.1	90.0
0.05	82.4	88.6
0.01	80.6	86.8
Mean	83.0	89.4

that could be quantitatively determined with suitable precision and accuracy. The limit of quantification (LOQ) – 0.01µg/g in fortified soil and chilli.

Degradation of metribuzin and residue dissipation: The decrease in residue levels during the days after application in soil is presented in **Figure 2**. The metribuzin residue level ranged 0.153–0.356 µg/g on the days after application (DAA) of metribuzin and observed up to the ranged 0.023 – 0.087 µg/g on the 21st DAA of metribuzin. The metribuzin residue level was observed at below detection limit (BDL) from 30th DAA of metribuzin. The dissipation of metribuzin in soil followed a pseudo first order kinetics (Khoury *et al*. 2006).The metribuzin degradation and dissipation is strongly dependent on temperature (Benoit *et al*. 2007). Application of organic manure significantly increased the retention of metribuzin in soil (Mazumdar and Singh 2007). Khoury *et al*. (2006) stated that soil microbes has important role in the rapid degradation of metribuzin in soil. Intense leaching was due to low adsorption of metribuzin in soil (Lagat *et al*. 2011).

The half life ($T_{1/2}$) and dissociation coefficient (k) calculated for single and double dose of applications were presented in **Table 2**, with a half-life of 7–10 days and dissociation coefficient of 0.07-0.09/days. The half-life of metribuzin is dependent on factors like soil moisture content, pH, temperature and depth of application (Smith and Walker 1989). Metribuzin in field soil have shorter half-life over that of sterile soil (Ivany *et al*. 1983) due to the presence of native microbial population in soil.

Table 2. Half life and dissociation coefficient

Rate of application	X (500 g/ha)	2X (1000 g/ha)
Half Life (T1/2) days	7.43 ± 0.23	10.33 ± 0.17
Dissociation coefficient (k)/days	0.093 ± 0.003	0.067 ± 0.005

Recovery investigation for validation of method used for sample preparation resulted acceptable range of (80.6-92.16%) for the substrates with the retention time of 3.097 minutes. The goodness of fit was 0.9899 for calibrating the standard curve of metribuzin, From the present investigation it can be concluded that there was no persistence of metribuzin residue in soil beyond 30 DAA and in fruits at harvest with a half life of 7–10 days. Therefore, the organic manure in soil is to be well incorporated to minimize the residue build up in soil.

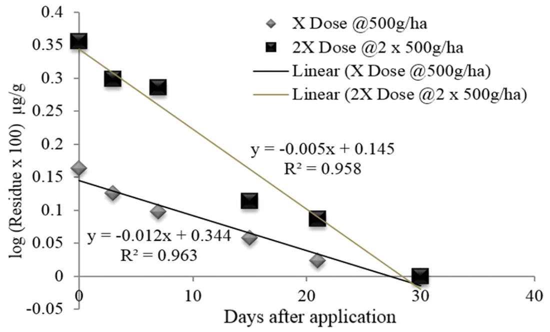

Figure 2. Dissipation of metribuzin in soil

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Integrated weed management in summer sorghum

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ABSTRACT

A field experiment was conducted at College Farm, Navsari Agricultural University, Navsari (Gujarat) during summer season 2016 to study the effect of integrated weed management practices on weed density, weed dry weight and economics in sorghum. The experiment was laid out in randomized block design with three replications and ten treatments with pre- and post-emergence herbicides (atrazine, 2,4-D and metsulfuron-methyl) alone or combination of these herbicides followed by hand weeding and inter-culturing operation. That two hand weeding and inter-culturing operations at 20 and 40 DAS significantly reduced weed density and dry weight of broad-leaved, grassy and sedge weeds. Weed control efficiency was recorded to the range of 52.50 - 97.00%, with the highest value in two hand weeding and inter-culturing operations at 20 and 40 DAS and lowest in atrazine 0.50 kg/ha as pre-emergence *fb* metsulfuron-methyl 6 g/ha as post-emergence. Higher net return of ` 54623/ha was obtained with two hand weeding and inter-culturing operations at 20 and 40 DAS followed by ` 50179/ha with atrazine 0.50 kg/ha as pre-emergence *fb* atrazine 0.50 kg/ha as post-emergence at 25 DAS.

Sorghum (*Sorghum bicolor* L.) is one of the major staple food crops in semi-arid tropics. In Gujarat. Sorghum occupies about 0.14 million ha area and annual production of 0.19 million tonnes with the productivity of 1.35 t/ha (Anon. 2016). Weeds are major problems in increasing productivity of the crop. It was reported that yield loss of sorghum due to weeds ranges from 15-97%, depending on the nature and density of weeds (Thakur *et al*. 2016). Weeds germinated fast and grow rapidly at an initial growth period of crops competing with the crop severely for growth resources, *viz*. nutrients, moisture, sunlight and space. The integration of herbicides with some cultural and mechanical methods can provide effective weed control. The integrated weed management is gaining importance for preventing yield losses and achieving higher input-use efficiency (Ishaya *et al*. 2007). Hence, present experiment was carried out to study the effect of integrated weed management practices on weed density, weed dry weight and economics in summer sorghum.

The experiment was conducted during summer season of 2016 at Navsari Agricultural University, Navsari (Gujarat), India. The soil of the experimental field was clayey in texture, dark grayish brown type and characterized by medium to poor drainage with good water holding capacity. The soil was low, medium and high in available nitrogen, phosphorus and potassium status, respectively. The experiment was tried in randomized block design with ten treatments (**Table 1**). Sorghum cv. '*GJ-42*' was sown on 16 February, 2016 in rows at 45 cm apart using seed rate of 15 kg/ha and was harvested on 2 June, 2016. The number of weed present in 1 m² area was counted at three random places in each plot using quadrate at 20, 60 DAS and harvest and classified into broad-leaved, grassy and sedge weeds and further their population was recorded. The weed dry weight was recorded by drying weeds in oven till attaining a constant weight and then transformed into g/m^2 by using formula of square root transformation. Weed index was calculated using formula suggested by Gill and Kumar (1969).

Effect on weeds

The dominant weed species in the field included grasses, *viz. Echinochloa crus-galli, Cynodon dactylon, Sorghum halepense, Digitaria sanguinalis*; major broad-leaf weeds, *viz. Amaranthus viridis,* *Alternanthera pungens, Digera arvensis, Convolvulus arvensis, Vernonia cinerea, Eclipta alba, Trienthema portulacastrum, Euphorbia hirta, Physalis minima*; and among sedges, *Cyperus rotundus* was dominantly present.

Two hand weeding (HW) and inter-culturing at 20 and 40 DAS recorded significantly lower number of all the weeds, *viz*. broad-leaved, grassy and sedge weeds per m^2 at 20, 60 DAS and harvest. Among the integrated weed management treatments, atrazine 0.50 kg/ha as pre-emergence (PE) *fb* atrazine 0.50 kg/ha as post-emergence (PoE) at 25 DAS *fb* HW and inter-culturing at 40 DAS recorded lower density of broad-leaved, grassy and sedge weeds (**Table 1**). The present results are in agreement with the earlier findings of Priya and Kubsad (2013).

The dry weight of weeds recorded at 40, 60 DAS and harvest in summer sorghum differed significantly due to weed management practices (**Table 2**). Significantly lower weeds dry weight was recorded with two HW and inter-culturing at 20 and 40 DAS. Among the integrated weed management treatments, atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS recorded lower weeds dry weight (2.07, 2.98 and 4.41 g/m^2 at 40, 60 DAS and harvest, respectively) as compared to other treatments. However, unweeded control recorded significantly higher dry weed biomass as compared to other weed management treatments. Similar result was also reported by Kumar *et al.* (2012).

All the weed management practices resulted in increased weed control efficiency over unweeded control (**Table 2**). The highest weed control efficiency (97.00%) was observed under two HW and inter-culturing at 20 and 40 DAS followed by treatment atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS (72.86%). Priya and Kubsad (2013) have also obtained similar effect of various weed control treatments on weed control efficiency. Weed index worked out at harvest of crop was found lowest under two HW and inter-culturing at 20 and 40 DAS (00.00%) followed by atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS (11.08%) (**Table 2**). This might be due to effective weed control achieved under these weed management treatments, which resulted in reduction of weeds biomass ultimately increase the crop yield in treated plots, which calculate lower weed index in a particular plots.

Table 1. Effect of weed management practices on broad-leaf, grassy and sedge weeds density at 20, 60 DAS and harvest in sorghum

Treatment	Weed density (no./m^2)								
	Broad-leaf			Grassy			Sedges		
	20 DAS	60 DAS	At harvest	20 DAS	60 DAS	At harvest	20 DAS	60 DAS	At harvest
Atrazine 1.0 kg/ha as PE	2.74 (7.0)	3.24 (10.0)	3.72 (13.3)	2.87 (7.8)	2.55 (6.0)	3.12 (9.3)	2.28 (4.7)	2.18 (4.3)	2.23 (4.5)
Atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS	2.67 (6.7)	3.08 (9.0)	3.13 (9.3)	2.86 (7.7)	2.23 (4.5)	2.45 (5.5)	2.24 (4.5)	2.08 (3.9)	2.17 (4.2)
Atrazine 0.50 kg/ha as PE *fb* 2, 4-D 0.50 kg/ha as PoE at 25 DAS	2.71 (6.8)	3.16 (9.5)	3.31 (10.4)	2.88 (7.8)	2.41 (5.3)	2.55 (6.0)	2.28 (4.7)	2.23 (4.5)	2.19 (4.3)
Atrazine 0.50 kg/ha as PE *fb* metsulfuron methyl 6 g/ha as PoE at 25 DAS	2.86 (7.7)	3.53 (12.0)	3.94 (15.0)	2.97 (8.3)	2.93 (8.1)	3.24 (10.0)	2.30 (4.8)	2.52 (5.9)	2.91 (8.0)
Atrazine 1 kg/ha as PE *fb* HW and inter-culturing at 40 DAS	2.63 (6.4)	3.03 (8.7)	3.06 (9.1)	2.80 (7.3)	2.16 (4.2)	2.41 (5.3)	2.21 (4.4)	1.95 (3.3)	2.11 (3.9)
Atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS	2.58 (6.1)	2.73 (7.0)	2.94 (8.2)	2.74 (7.0)	2.03 (3.7)	2.23 (4.5)	2.09 (3.9)	1.86 (3.0)	1.95 (3.3)
Atrazine 0.50 kg/ha as PE *fb* 2, 4-D 0.50 kg/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS	2.61 (6.3)	2.86 (7.7)	2.99 (8.5)	2.80 (7.3)	2.12 (4.0)	2.37 (5.2)	2.20 (4.3)	1.90 (3.1)	2.07 (3.8)
Atrazine 0.50 kg/ha as PE *fb* metsulfuron methyl 6 g/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS	2.76 (7.1)	3.33 (10.6)	3.85 (14.3)	2.92 (8.0)	2.80 (7.3)	3.21 (9.8)	2.27 (4.7)	2.32 (4.9)	2.73 (7.0)
Unweeded control	2.91 (8.0)	4.56 (20.3)	5.15 (26.0)	3.08 (9.0)	3.94 (15.0)	4.18 (17.0)	2.34 (5.0)	3.01 (8.6)	3.39 (11.0)
Two HW and inter-culturing at 20 and 40 DAS	2.54 (6.0)	1.47 (1.7)	1.86 (3.0)	2.55 (6.0)	1.47 (1.7)	1.58 (2.0)	1.94 (3.3)	1.56 (1.9)	1.50 (1.7)
LSD (p=0.05)	NS	0.23	0.31	0.26	0.23	0.20	0.22	0.20	0.18

Figures in parentheses are original values; PE - Pre-emergence; PoE - Post-emergence

Table 2. Effect of weed management practices on weed dry weight, weed control efficiency, weed index, seed yield and net returns in sorghum

Treatment	Weed dry weight (g/m^2)			Weed control efficiency (%)	Weed index (%)	Seed yield (t/ha)	Net returns (x10^3 `/ha)
	40 DAS	60 DAS	At harvest				
Un weeded control	*4.62(20.8)	6.96(47.9)	8.40(70.2)	0.0	34.48	2.16	35.56
Two HW and inter-culturing at 20 and 40 DAS	1.60(2.1)	1.50(1.8)	1.61(2.1)	97.0	0.00	3.30	54.62
Atrazine 1.0 kg/ha as PE	2.55(6.0)	3.40(11.1)	5.34(28.0)	60.0	21.95	2.58	45.76
Atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS	2.34(5.0)	3.22(9.9)	5.26(27.2)	61.3	15.92	2.78	50.18
Atrazine 0.50 kg/ha as PE *fb* 2, 4-D 0.50 kg/ha as PoE at 25 DAS	2.45(5.5)	3.27(10.2)	5.33(28.0)	60.1	20.83	2.61	46.74
Atrazine 0.50 kg/ha as PE *fb* metsulfuron methyl 6 g/ha as PoE at 25 DAS	3.29(10.3)	3.59(12.5)	5.82(33.4)	52.5	29.06	2.34	39.23
Atrazine 1 kg/ha as PE *fb* HW and inter-culturing at 40 DAS	2.29(4.8)	3.15(9.4)	5.08(25.3)	63.8	15.11	2.80	46.64
Atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS	2.07(3.8)	2.98(8.4)	4.41(19.0)	72.9	11.08	2.94	49.75
Atrazine 0.50 kg/ha as PE *fb* 2, 4-D 0.50 kg/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS	2.16(4.2)	3.09(9.1)	4.85(23.0)	67.2	13.20	2.87	48.14
Atrazine 0.50 kg/ha as PE *fb* metsulfuron methyl 6 g/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS	3.21(9.8)	3.41(11.2)	5.54(30.3)	56.9	25.73	2.45	37.43
LSD (p=0.05)	0.24	0.29	0.37	-	-	0.56	-

Figures in parenthesis are original values; PE - Pre-emergence; PoE - Post-emergence

Effect on sorghum

All the weed management treatments resulted in significantly higher seed yield than the unweeded control (**Table 2**). Two HW and inter-culturing at 20 and 40 DAS recorded significantly higher seed yield of sorghum (3.30 t/ha) followed by atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS *fb* HW and inter-culturing at 40 DAS (2.94 t/ha) over unweeded control (2.16 t/ha) (**Table 2**). Two hand weeding and inter-culturing at 20 and 40 DAS recorded maximum net return (` 54,623/ha) followed by atrazine 0.50 kg/ha as PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS (` 50,179/ha) and atrazine 0.50 kg/ha PE *fb* atrazine 0.50 kg/ha as PoE at 25 DAS *fb* HW and IC at 40 DAS (` 49,749/ha), whereas unweeded control recorded lowest net return (` 35,559/ha) (**Table 2**).

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