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Eco-efficacy of pretilachlor 50% EC in transplanted winter rice and its residual effect on lentil

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ABSTRACT

A field experiment was conducted during *Kharif* seasons of 2014-15 and 2015-16 at Bidhan Chandra Krishi Viswavidyalaya (BCKV), West Bengal to evaluate the effect of pretilachlor 50% EC on growth of composite weed flora and productivity of winter (*Kharif*) rice (*Oryza sativa* L.). The experiment comprised of eight treatments following a randomized block design with three replications. Experimental findings revealed that hand weeding twice at 15 and 30 DAT effectively controlled the grasses, sedges and broad-leaved weeds, which recorded statistical parity with the application of pretilachlor 50% EC at 750 g/ha followed by its lower dose at 600 g/ha. Grain yield losses amounted to 31.4-50.1% due to uncontrolled weed growth as compared to different weed control treatments. Among the different herbicidal treatments, pretilachlor 50% EC at 750 and 600 g/ha recorded higher weed control efficiency, yield attributes and grain yield (4.25 and 4.20 t/ha, respectively) of rice, which did not affect the germination and seed yield of succeeding lentil crop during both the years. Besides, soil beneficial microflora was not negatively influenced in long run. Considering bio-efficacy, economics and microbial study, pretilachlor 50% EC at 600 g/ha could be a better alternative for weed management and may be recommended for obtaining a higher yield of transplanted winter rice in the Gangetic Inceptisol of West Bengal.

INTRODUCTION

Rice plays an important role in food as well as livelihood security for almost every household, particularly to the farmers of Gangetic Inceptisol of India (Mondal *et al.* 2018). The production of rice in this region plays a vital role in maintaining food sufficiency in India. At the current growth rate of population (1.55%) in India, the requirement of rice by 2020 would be around 120-135 million tonnes (Raj *et al.* 2016). For maintaining food security, it is quite important to lift up the productivity levels of rice and that too by facing the adverse impacts of climate change. Weeds are claimed to be one of the major yield limiting factors in rice crop. It implies a serious negative effect on crop production and responsible for 45-55% reduction of grain yield (Ghosh *et al.* 2013) under severe infestation. If we can minimize this amount of crop losses, the rice productivity could be brought to the desired level. Therefore, weed control measures at critical crop weed competition period are gaining more importance (Mondal *et al.* 2017). Manual weeding is common in India, but its use is declining due to labour scarcity at the critical time of weeding and also for increasing labour wages (Duary *et al.* 2015). Chemical weed management through herbicides is low-cost alternative, but still needs more eco-sustainable and farmers' acceptance. According to Saha (2005), herbicides offer selective and economic control of weeds by giving the crop an advantage of good start and competitive superiority. Several new pre- and post-emergence herbicides are introducing in a regular manner but their ecosafe low-cost efficiency needs to be investigated. Pretilachlor [2-chloro-N-2,6-diethyl-N-(2-propoxyethyl) acetanilide], a chloro-acetanilide herbicide is used for the control of a broad spectrum of weeds in rice fields. In view of the above facts, it would be desirable to find out some alternative herbicides that can provide better control against diverse weed flora (grasses, sedges and broad-leaved) under transplanted condition.

MATERIALS AND METHODS

A field experiment was conducted during 2014-15 and 2015-16 at 'C' Block farm (latitude: 22°57'E, longitude: 88°20'N and altitude: 9.75 m) of Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal. Each plot size was of 5 × 4m. The experimental soil was well drained, alluvial in nature and sandy loam in texture, having pH 6.91, organic carbon 0.589%, available nitrogen 243.57 kg/ha, available P_2O_5 22.85 kg/ha and available K_2O 238.18 kg/ha (Jackson, 1967).

The treatments comprised of new herbicide formulation pretilachlor 50% EC in different doses (500, 600 and 750 g/ha) along with pretilachlor 37% EW at 650 g/ha, butachlor 50% EC at 1250 g/ha and cyhalofop butyl 10% EC at 80 g/ha. All the herbicides were sprayed as pre-emergence at 3 days after transplanting (DAT) while cyhalofop-butyl was applied as post-emergence at 20 days after transplanting (DAT). Hand weeding twice (15 and 30 DAT) was also included in the experiment besides the un-weeded control (weedy check).

The experiment was studied in a randomized block design with three replications. All data were analyzed through analysis of variance (ANOVA) using standard variance techniques suggested by Gomez and Gomez (1984). Weed data were subjected to square-root transformation [$(\sqrt{x+1})$] before statistical analysis to improve the homogeneity of variance. Treatment means were separated using least significant difference (LSD) at 5% level of significance ($\sqrt{x+0.5}$).

Rice (variety '*IET-4786*') was transplanted during last week of July in two consecutive years with full doses of phosphorus through single super phosphate and potash through muriate of potash each at 30 kg/ha at basal. The recommended dose of nitrogen at 60 kg/ha through urea was applied in 4 splits at 10, 25, 45 and 65 DAT. All the recommended improved package of practices of transplanted rice was followed in this experiment including the general plant protection measures. The herbicides were applied with a knapsack sprayer having a delivery of about 500 L/ha of spray solution through a flat fan nozzle at a spray pressure of 140 kPa.

The efficacy of the herbicides was evaluated at 20 and 40 days after herbicide application (DAA). At each sampling time, three quadrates of 50 × 50 cm were placed randomly in each plot to determine the density and biomass of weeds. Weeds were uprooted manually, identified and counted into three groups (grasses, sedges, and broad-leaved). Samples were then sun-dried for 24 hours and then oven-dried at 70°C for 72 hours. The dry weight of weeds was then taken and recorded separately. To compare the efficacy of different herbicidal treatments, weed control efficiency (WCE), weed control index (WCI), weed management index (WMI), agronomic management index (AMI), herbicide efficiency index (HEI) and integrated weed management index (IWMI) were calculated using formulae as given by Das (2013).

For microbial study, the requisite composite samples of each treatment from the experimental plots were collected at a depth 0-15 cm at before and after (7, 15, 30 DAA and at harvesting of rice) spraying of herbicides. Enumeration of microbial population was done on agar plate containing appropriate media following serial dilution technique and pour plate method (Pramer and Schmidt, 1965). Plates were incubated at 30°C and counts were taken on the 3rd day of incubation.

Residual study of tested herbicides was done on follow-up lentil crop (cv. Subrata), grown in the same plot without disturbing the previous field lay-out. Seeds were sown after treated with *Trichoderma viride* at 4 g/kg of seed at a spacing of 30 × 10 cm. All plots received a basal fertilizer application of 20 kg nitrogen/ha as urea, 40 kg phosphorus/ha as single super phosphate and 40 kg potassium/ha as muriate of potash. All the recommended improved package of practices was followed in lentil. Germination% along with the density of lentil crop was recorded at 30 days after sowing (DAS).

RESULTS AND DISCUSSION

Status of the weed flora

In the experimental plots, the dominant weed flora were comprised of *Echinochloa colona*, *Echinocloa formosensis*, *Leersia hexandra* (grassy weeds) and *Cyperus difformis* (sedge), while *Ammania baccifera* and *Alternanthera philoxeroides* were dominant among broad-leaf weeds.

Effect of treatments on weed density

Results showed significant differences among the herbicidal treatments for the weed density of grass, sedge and broad-leaf species at different days of observation **(Table 1)**. Maximum weed density (of all categories as well as total) was recorded in weedy check plots. The weed density showed that the testing pretilachlor 50% EC gave better result in controlling both monocot and dicot weeds very effectively and its efficacy was more with higher doses. Better efficacy was obtained from testing pretilachlor 50% EC at 750 g/ha and was at par with its lower dose at 600 g/ha. The lowest total weed density was recorded in the treatment hand weeding twice at 15 and 30 DAT (4.55 no./m^2 at 20 DAA and 4.58 no./m^2 at 40 DAA) followed by the treatment pretilachlor 50% EC at 750 g/ha (6.01 no./m^2 at 20 DAA and 13.12 no./m^2 at 40 DAA) and its lower doses. Pretilachlor 37% EW at 650 g/ha, butachlor 50% EC at 1250 g/ha and cyhalofop butyl 10% EC at 80 g/ha were also able to minimize total weed density but the population was higher than the treatments treated with pretilachlor 50% EC at 750 and 600 g/ha. The results were in conformity with the findings of Dharumarajan *et al* (2009).

Effect of treatments on weed biomass

The highest total weed biomass was recorded in the plots that received practically no weed control measures (weedy check), which was significantly differed ($p < 0.05$) from all other herbicidal treatments. Hand-weeding recorded lowest dry matter of weeds probably due to effective control of the first flush of weeds during 15–30 DAT and second flush of weeds from 30 DAT onwards. The findings were in line with the findings of Suganthi *et al.* (2005). Herbicidal weed control treatments significantly affected all categories of weeds (grass, sedge and broad-leaved), and the lowest total weed biomass was recorded **(Table 2)** in the plots that received pretilachlor 50% EC at 750 g/ha (3.27 g/m^2 at 20 DAA and 7.82 g/m^2 at 40 DAA) followed by the treatments treated with pretilachlor 50% EC at 600 g/ha (3.81 g/m^2 at 20 DAT and 9.01 g/m^2 at 40 DAA), pretilachlor 50% EC at 500 g/ha (4.54 g/m^2 at 15 DAA and 10.05 g/m^2 at 30 DAA), butachlor 50% EC at 1250 g/ha (6.42 g/m^2 at 15 DAA and 12.55 g/m^2 at 30 DAA) and cyhalofop butyl 10% EC at 80 g/ha (9.78 g/m^2 at 15 DAA and 17.67 g/m^2 at 30 DAA).

Impact assessment

Weed management indices provide a logistic support in impact assessment, interpretations and drawing appropriate conclusions in weed management research. Here in this experiment, WCE and WCI of different weed control measures was higher during initial stages of growth (20 DAA), and it was declined with time **(Table 3)**. Total WCE was recorded maximum in hand weeding treatment (85.9% at 20 DAA and 75.5% at 40 DAA) compared to other treatments. Among the tested herbicides,

Table 1. Effect of weed control treatments on weed density in rice (pooled over two years)

Treatment	Weed density (no./m^2)							
	20 days after herbicide application				40 days after herbicide application			
	Grass	Sedge	Broad-leaved	Total	Grass	Sedge	Broad-leaved	Total
Pretilachlor 50% EC at 500g/ha	3.2(2.05)	2.2(1.79)	3.0(2.00)	8.4(3.07)	6.2(2.69)	4.0(2.24)	6.9(2.24)	17.1(4.26)
Pretilachlor 50% EC at 600 g/ha	2.4(1.86)	2.0(1.73)	2.7(1.92)	7.1(2.85)	5.2(2.49)	3.7(2.16)	6.1(2.16)	15.0(4.00)
Pretilachlor 50% EC at 750 g/ha	1.9(1.70)	1.9(1.70)	2.2(1.79)	6.0(2.65)	4.4(2.34)	3.2(2.05)	5.4(2.05)	13.1(3.76)
Pretilachlor 37% EW at 650 g/ha	3.9(2.21)	2.6(1.89)	3.8(2.18)	10.2(3.35)	5.7(2.58)	3.9(2.21)	6.4(2.21)	16.0(4.12)
Butachlor 50% EC at 1250 g/ha	5.3(2.52)	2.9(1.97)	5.4(2.54)	13.7(3.83)	8.3(3.06)	4.8(2.40)	9.4(2.40)	22.6(4.85)
Cyhalofop-butyl 10% EC at 80 g/ha	6.6(2.75)	3.9(2.21)	7.0(2.83)	17.4(4.30)	9.3(3.21)	7.9(2.98)	16.7(2.98)	33.9(5.91)
Hand weeding at 15 and 30 DAT	1.3(1.53)	1.4(1.56)	1.8(1.67)	4.5(2.36)	1.5(1.57)	1.2(1.49)	1.9(1.70)	4.6(2.36)
Weedy check	8.6(3.10)	8.9(3.15)	14.7(3.97)	32.3(5.77)	12.3(3.65)	12.7(3.70)	20.3(3.70)	45.3(6.81)
LSD (p=0.05)	0.016	0.014	0.017	0.031	0.023	0.019	0.020	0.043

Data in parentheses are square root transformed value ($\sqrt{x+1}$) and used for statistical analysis

Table 2. Effect of weed control treatments on weed biomass in rice (pooled over two years)

Treatment	Weed biomass (g/m^2)							
	20 days after herbicide application				40 days after herbicide application			
	Grass	Sedge	Broad-leaved	Total	Grass	Sedge	Broad-leaved	Total
Pretilachlor 50% EC at 500g/ha	1.6(1.60)*	1.1(1.44)	1.9(1.71)	4.5(2.35)	3.5(2.13)	2.2(1.79)	4.3(2.30)	10.1(3.32)
Pretilachlor 50% EC at 600 g/ha	1.3(1.50)	0.9(1.39)	1.6(1.62)	3.8(2.19)	3.0(2.01)	2.0(1.73)	3.9(2.23)	9.0(3.16)
Pretilachlor 50% EC at 750 g/ha	1.1(1.44)	0.8(1.35)	1.4(1.54)	3.3(2.07)	2.7(1.93)	1.9(1.70)	3.2(2.06)	7.8(2.97)
Pretilachlor 37% EW at 650 g/ha	1.3(1.54)	0.9(1.41)	1.7(1.67)	4.1(2.27)	3.1(2.04)	2.1(1.75)	4.1(2.26)	9.3(3.21)
Butachlor 50% EC at 1250 g/ha	2.2(1.80)	1.3(1.52)	2.8(1.97)	6.4(2.73)	4.3(2.31)	2.7(1.91)	5.5(2.56)	12.5(3.68)
Cyhalofop-butyl 10% EC at 80 g/ha	2.4(1.85)	1.7(1.64)	5.7(2.59)	9.7(3.28)	4.6(2.36)	3.8(2.21)	9.2(3.20)	17.6(4.32)
Hand weeding at 15 and 30 DAT	0.9(1.37)	0.6(1.29)	1.2(1.49)	2.7(1.93)	0.9(1.39)	0.7(1.31)	1.5(1.57)	3.1(2.03)
Weedy check	5.4(2.52)	3.9(2.21)	7.5(2.92)	16.7(4.21)	8.6(3.10)	5.8(2.62)	12.3(3.65)	26.7(5.27)
LSD (p=0.05)	0.011	0.007	0.012	0.086	0.017	0.012	0.018	0.028

Data in parentheses are square root transformed value ($\sqrt{x+1}$) and used for statistical analysis

Table 3. Effect of weed control treatments on weed control efficiency and weed control index in rice (mean data of two years)

Treatment	20 days after herbicide application				40 days after herbicide application			
	Grass	Sedge	Broad-leaves	Total	Grass	Sedge	Broad-leaves	Total
Weed control efficiency (%)								
Pretilachlor 50% EC at 500g/ha	62.69	75.14	79.65	73.87	49.59	68.43	66.13	62.27
Pretilachlor 50% EC at 600 g/ha	71.61	77.60	81.89	77.96	57.70	71.03	69.96	66.92
Pretilachlor 50% EC at 750 g/ha	77.98	78.84	84.94	81.39	63.94	74.59	73.21	71.07
Pretilachlor 37% EW at 650 g/ha	55.04	71.33	74.42	68.39	54.05	69.30	68.34	64.72
Butachlor 50% EC at 1250 g/ha	38.12	67.64	63.03	57.65	32.41	62.27	53.59	50.25
Cyhalofop-butyl 10% EC at 80 g/ha	23.99	56.44	52.51	45.98	24.39	37.73	18.04	25.27
Hand weeding at 15 and 30 DAT	84.59	83.87	87.92	85.91	69.37	77.19	78.12	75.48
Weedy check	-	-	-	-	-	-	-	-
Weed control index (%)								
Pretilachlor 50% EC at 500g/ha	70.95	72.54	74.54	72.93	58.72	62.22	65.12	62.43
Pretilachlor 50% EC at 600 g/ha	76.54	76.17	78.38	77.28	64.88	65.81	67.56	66.32
Pretilachlor 50% EC at 750 g/ha	79.89	78.76	81.83	80.50	68.49	67.86	73.74	70.77
Pretilachlor 37% EW at 650 g/ha	74.30	74.61	76.39	75.31	63.26	64.79	66.75	65.20
Butachlor 50% EC at 1250 g/ha	58.47	65.80	61.94	61.72	49.42	54.53	54.96	53.08
Cyhalofop-butyl 10% EC at 80 g/ha	55.12	56.74	24.40	41.68	47.09	33.50	24.96	33.94
Hand weeding at 15 and 30 DAT	83.61	82.64	83.95	83.54	72.09	71.79	75.45	73.57
Weedy check	-	-	-	-	-	-	-	-

Table 4. Bio-efficiency of different weed control treatments in rice (mean data of two years)

Treatment	Herbicide efficiency index	Weed management index	Agronomic management index	Integrated weed management index	Weed persistence index
Pretilachlor 50% EC at 500 g/ha	1.12	1.60	0.60	1.10	1.02
Pretilachlor 50% EC at 600 g/ha	1.33	1.64	0.64	1.14	1.03
Pretilachlor 50% EC at 750 g/ha	1.56	1.66	0.66	1.16	1.03
Pretilachlor 37% EW at 650 g/ha	1.24	1.63	0.63	1.13	0.92
Butachlor 50% EC at 1250 g/ha	0.78	1.52	0.52	1.02	0.93
Cyhalofop-butyl 10% EC at 80 g/ha	0.50	1.46	0.46	0.96	0.95
Hand weeding at 15 and 30 DAT	1.80	1.68	0.68	1.18	1.12
Weedy check	-	-	-	-	1.00

pretilachlor 50% EC at 750 g/ha recorded maximum WCE (total) 81.4% and 71.1% at 20 and 40 DAA respectively, which was closely followed by its next dose pretilachlor 50% EC at 600 g/ha and these treatments were superior to all other treatments with respect to WCE. These findings were in line with the findings of Narayanan *et al.* (2000), Suganthi *et al.* (2005) and Kumar *et al.* (2007). WCI was derived on the basis of weed dry weight. Therefore, WCI obtained initially was higher and then decreases as the crop growth advances towards maturity. This all happens due to dry weight normally goes on increasing over time at the later stage of crop growth under herbicide-treated plot, since during this period herbicide loss its bio-efficacy. Among the herbicidal treatments, pretilachlor 50% EC at 750 g/ha exhibited higher HEI, WMI, AMI **(Table 4)** as compared to other tested herbicides which was closely followed by its next dose at 600 g/ha. That means the above treatment showed higher bio-efficacy in controlling different categories of weeds in rice ecosystem resulting higher IWMI.

Effect of herbicides on phytotoxicity

No phytotoxic symptoms such as epinasty/ hyponasty, leaf yellowing, necrosis, stunting growth, wilting etc were found in rice as well as succeeding lentil crop.

Effects on yield attributes and yield of rice

All weed management treatments showed significantly higher values of yield attributes and yield over the weedy check due to the effective suppression of weeds resulting in more soil aeration, enhanced uptake of inputs like nutrients, light, moisture by crop and lesser weed competition during critical crop weed competition period (Mondal *et al.* 2017). Yield attributes like number effective panicles/ m^{-2} (338 and 318 numbers during 2014-15 and 2015-16 respectively) and number of filled grains/panicle (85.33 and 84.33 numbers during 2014-15 and 2015-16 respectively) were found higher under hand weeded treatment which was closely followed by the treatment treated with pretilachlor 50% EC at 750 and

600 g/ha **(Table 5)**. Similar result was also observed by Suganthi *et al.* (2005). Grain yield losses amounted to 31.4-50.1% due to uncontrolled weed growth as compared to different weed control treatments. Similar yield reduction in rice due to weed competition in the Gangetic alluvial zone of West Bengal was also reported by Mondal *et al.* (2018) and Duary (2014). Hand weeding (4.44 and 4.18 t/ha during 2014-15 and 2015-16, respectively) treatment recorded maximum grain yield of rice followed by pretilachlor 50% EC at 750 g/ha (4.34 and 4.16 t/ha during 2014-15 and 2015-16, respectively) and pretilachlor 50% EC at 600 g/ha (4.26 and 4.14 t/ha during 2014-15 and 2015-16, respectively). Similar trend was also followed in straw yield of rice. The higher assimilation of photosynthates in herbicide treated plots may be the reason for higher yield attributes and ultimately higher yield in rice under transplanted condition (Dharumarajan *et al.* 2009 and Mondal *et al.* 2017).

Economics

Pretilachlor 50% EC recorded higher benefit: cost ratio than other herbicidal treatments along with twice hand weeding **(Table 5)**. Among the weed-control treatments, pretilachlor 50% EC at 600 g/ha (1.91 and 1.89 during 2014-15 and 2015-16, respectively) recorded maximum benefit: cost ratio followed by pretilachlor 50% EC at 750 g/ha (1.82 and 1.84 during 2014-15 and 2015-16, respectively). Though twice hand weeding topped in grain yield but ever increasing rate of labour wages makes this treatment costly and it fetched significantly lower benefit:cost ratio (1.25 and 1.19 during 2014-15 and 2015-16, respectively) as compared to herbicidal treatments. The higher benefit: cost ratio under these testing herbicide treatments was mainly owing to more grain yield and comparatively lower variable cost of cultivation compared to manual weeding and the other herbicidal treatments (Kashid *et al.* 2016).

Table 5. Effect of weed control treatments on yield attributes, yield and economics of rice

Treatment	No. of effective panicle/m^{-2}		No. of filled prains/ panicle		Grain yield (t/ha)		Straw yield (t/ha)		Benefit: Cost Ratio	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pretilachlor 50% EC at 500 g/ha	320	302	79.33	78.00	4.13	4.05	5.23	4.75	1.63	1.65
Pretilachlor 50% EC at 600 g/ha	328	306	80.33	82.33	4.26	4.14	5.31	5.19	1.91	1.89
Pretilachlor 50% EC at 750 g/ha	334	310	82.67	83.99	4.34	4.16	5.57	5.39	1.82	1.84
Pretilachlor 37% EW at 650 g/ha	322	304	79.67	81.67	4.22	4.10	5.18	5.06	1.70	1.66
Butachlor 50% EC at 1250 g/ha	312	292	75.67	74.99	3.91	3.87	4.65	4.61	1.53	1.51
Cyhalofop butyl 10% EC at 80 g/ha	298	276	70.67	73.99	3.82	3.64	4.38	4.20	1.38	1.40
Hand weeding at 15 and 30 DAT	338	318	85.33	84.33	4.44	4.18	5.95	5.43	1.25	1.19
Weedy check	209	233	54.33	67.00	2.71	2.41	2.99	2.69	0.97	0.97
LSD (p=0.05)	7.79	5.07	0.79	0.47	0.10	0.11	0.17	0.16	-	-

Table 6. Correlation matrix among the weed density and dry weight and yield components of rice (mean data of two years)

	Weed density (no./m^2)	Weed biomass (g/m^2)	Effective panicles (no./m^2)	Filled grains (no./ panicle)	Grain yield (t/ha)	Straw yield (t/ha)
Weed density (no./m^2)	1					
Weed biomass (g/m^2)	0.997**	1				
No. effective panicles/m^2	-0.979**	-0.987**	1			
No of filled grains/panicle	-0.991**	-0.990**	0.982**	1		
Grain yield (t/ha)	-0.971**	-0.982**	0.998**	0.978**	1	
Straw yield (t/ha)	-0.990**	-0.989**	0.988**	0.999**	0.982**	1

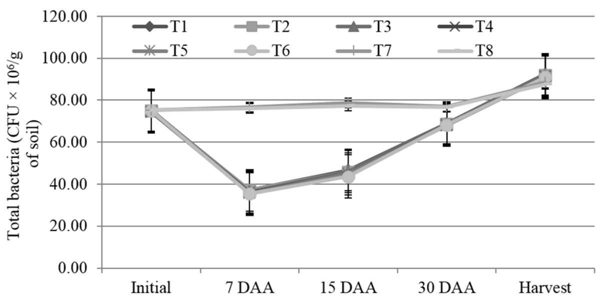
**Correlation is significant at the 0.01 level (2-tailed)

Correlation matrix

Weed density and biomass had registered significantly negative correlation with all the yield attributes and yield of rice **(Table 6)**. While the entire yield attributes (number of effective panicles/m^{-2}, number of filled grains/panicle) and biological yield parameters (grain and straw yield) were significantly positively correlated among themselves. Weed density and biomass had a strong negative correlation with grain yield (r=-0.917** and r=-0.982** respectively) of rice. These findings were in line with the findings of Mondal *et al.* (2018).

Effect on soil microorganism

Soil microorganisms *viz.* total bacteria, fungi and actinomycetes **(Figure 1-3)** did not show any significant influence on the population in *Rhizosphere* soil at initial stage. Though after the application of the chemicals significant variations were found between



T_1= Pretilachlor at 500 g/ha; T_2= Pretilachlor at 600 g/ha; T_3= Pretilachlor at 750 g/ha; T_4= Pretilachlor at 650 g/ha; T_5= Butachlor at 1250 g/ha; T_6= Cyhalofop-butyl at 80 g/ha; T_7= Hand weeding at 15 and 30 DAT; T_8= Weedy check

Figure 1. Effect of weed control treatment on total bacteria (CFU × 10^6/g of soil) population

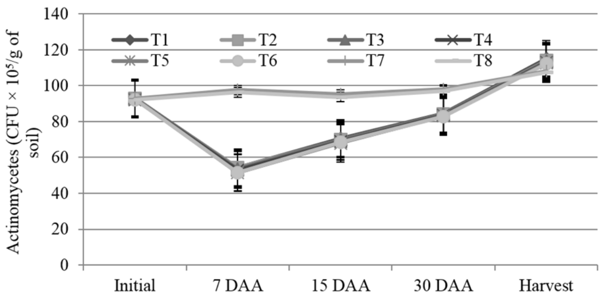


Figure 2. Effect of weed control treatment on actinomycetes (CFU × 10^5/g of soil) population

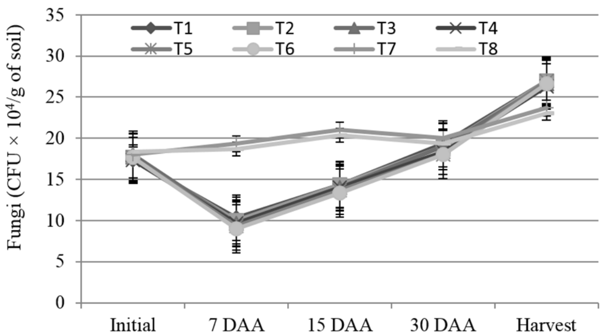


Figure 3. Effect of weed control treatment on fungi (CFU × 10^4/g of soil) population

the treated and non-treated plotsdue to competitive influence and the toxic effect as well as different persistence periods of different chemical herbicides in different soil ecosystems. In addition, the increase was affected by the commensalic or proto-cooperative influence of various microorganisms on total bacteria in the rhizosphere of rice. For all the cases of herbicidal treatments, total bacteria recovered from initial loss and exceeded the initial counts (Ghosh *et al.* 2012). Regarding actinomycetes, the results might be due to the competitive influence of various microorganisms on the population of actinomycetes in the rhizosphere of rice as well as toxic effect of the chemicals applied (Sapundjieva *et al.* 2008). The pattern of population change of fungi might be due to the toxic effect or competitive influence of various microorganisms on the population of fungi in the rhizosphere soil of rice. But at harvesting the recorded population again did not differ significantly. Murato *et al.* (2004) observed that pretilachlor at 0.45 kg/ha was not appreciably affect the soil microbial communities.

Microorganisms are able to degrade herbicides and utilize them as a source of biogenic elements for their own physiological processes. However, before degradation, herbicides have toxic effects on microorganisms, reducing their abundance, activity and consequently, the diversity of their communities. The toxic effects of herbicides are normally most severe immediately after application, when their concentrations in soil are the highest. Later on, microorganisms take part in a degradation process, and herbicide concentration and its toxic effect gradually decline up to half-life. Then the degraded organic herbicide provides the substrate with carbon, which leads to an increase of the soil microflora.

Effect on succeeding crop

Germination percentage and population density and of lentil crop was recorded at 30 DAS **(Table 7)**. The recorded data did not show any significant variation among the treatments used in the previous rice crop. The seed yield data **(Table 7)** also did not vary significantly among the treatments where the pretilachlor 50% EC was used in different doses at 500, 600 and 750 g/ha in the previous crop.

So, from the above study, it may be concluded that pretilachlor 50% EC at 600 g/ha can profitably and safely be used to replace the tedious,time consuming and expensive handweeding practice for weed control in transplanted winter rice in the Gangetic Inceptisol of West Bengal.

Table 7. Effect of weed control treatments on succeeding lentil crop (pooled over two years)

Treatment	Effect of herbicides on succeeding lentil		
	Germination (%)	Population/ m^2 at 30 DAS	Seed yield (t/ha)
Pretilachlor at 500 g/ha	32.33	88.0	0.86
Pretilachlor at 600 g/ha	34.00	88.0	0.88
Pretilachlor at 750 g/ha	33.33	87.0	0.90
Pretilachlor at 650 g/ha	33.00	87.5	0.88
Butachlor at 1250 g/ha	33.67	86.5	0.84
Cyhalofop-butyl at 80 g/ha	32.00	87.0	0.84
Hand weeding at 15 and 30 DAT	34.00	88.0	0.93
Weedy check	33.67	88.5	0.83
LSD (p=0.05)	NS	NS	NS

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Efficacy of pendimethalin and cyhalofop-butyl + penoxsulam against major grass weeds of direct-seeded rice

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ABSTRACT

Direct-seeded rice (DSR) helps in saving water and is beneficial for soil physical health along with environmental benefits, but weeds poses a serious threat to efficient crop production. In the absence of ponded water, weeds emerge in several flushes making it difficult to manage them with a single pre- or post-emergence herbicide application. Studies were carried out under the screen house conditions at CCS Haryana Agricultural University, Hisar, where the response of four dominant grass weeds of direct-seeded rice, *viz*. *Echinochloa glabrescens*, *Leptochloa chinensis*, *Eragrostis japonica* and *Dactyloctenium aegyptium* was evaluated against pendimethalin and cyhalofop-butyl + penoxsulam mixture. The four grassy weed species were planted in pots replicated four time with 20 seed per plot. Pendimethalin was applied as pre-emergence at 0.25, 0.5, 1.0 and 2.0 kg/ha and cyhalofop-butyl + penoxsulam mixture was sprayed as post-emergence (PoE) (at 25 days after sowing) at 32.5, 65, 135 and 270 g/ha with the help of knapsack sprayer and control pots were maintained for each species and herbicides. Periodical observations on visual mortality (0-100 scale, where 0 = no effect and 100=complete mortality) and dry weight per pot was observed at harvest. Application of pendimethalin at 1.0 kg/ha resulted in excellent control of *L. chinensis* and *D. aegyptium*, whereas at 2.0 kg/ha application rate killed all the weeds. Cyhalofop-butyl + penoxsulam applied at 270 g/ha showed 100% mortality of *E. glabrescens* and *L. chinensis.* However, the highest rate (270 g/ha) of this mixture had no effect on *E. japonica*, and provided only 20% control of *D. aegyptium*. Results of this study suggest that pendimethalin can be used for managing *E. glabrescens*, *L. chinensis*, *E. japonica* and *D. aegyptium*. However, cyhalofop-butyl + penoxsulam can be used as PoE in fields dominated by *E. glabrescens* and *L. chinensis*.

INTRODUCTION

Choice of herbicide in rice crop varies according to the method of crop establishment because water regime varies with the method adapted. Different pre-emergence (pendimethalin, oxadiazon, oxadiargyl, pretilachlor, pyrazosulfuron *etc*.) and post-emergence (bispyribac-sodium, penoxsulam, fenoxaprop, azimsulfuron, 2,4-D, metsulfuron-methyl, chlorimuron + metsulfuron *etc*.) herbicides are used throughout the rice growing areas across the world (Chauhan 2012). There is a long window of emergence of weeds and also the infestation of a complex weed flora during the rainy season in direct seeded rice (DSR) fields, so one time application of herbicide may not effectively solve the weed problem (Bhullar *et al.* 2016, Singh 2016). Herbicides have to be applied in sequence or in mixtures for effective control of broad spectrum weed flora (grasses, broad-leaf weeds and sedges). Pre-emergence (PE) herbicides offer very limited window of application and they also require optimum moisture conditions at the time of sowing. PE herbicides in DSR can be applied 0-3 days after sowing (DAS) and if there is concurrence of pre monsoon showers in this short duration, farmer is left out with the only option of post-emergence (PoE) herbicides (Mahajan and Chauhan 2015). Hence, application of several herbicides in combination or in sequence is more useful than single application in DSR.

In DSR, major grass weeds being observed are *Echinochloa glabrescens*, *Leptochloa chinensis*, *Eragrostis japonica* and *Dactyloctenium aegyptium* (Mahajan and Chauhan 2013). The infestation of *L. chinensis* is increasing due to poor efficacy of many herbicides such as bispyribac-sodium and penoxsulam against this weed (Brar and Bhullar 2012), but it can be effectively managed by penoxalum + cyhalofop-methyl (Bhullar *et al.* 2016). Similarly penoxsulam is not effective for *D. aegyptium* control. Therefore, for complex weed flora control in DSR, we have to identify different herbicides, which can be applied alone or in combination as PE or PoE or sequential application of PE followed by PoE herbicides (Mahajan and Chauhan 2015). Therefore, keeping in view the present studies were conducted to determine the effectiveness of pendimethalin and cyhalofop-butyl + penoxsulam against four dominant weeds of DSR under controlled conditions which may be helpful for designing chemical weed management program for a particular DSR field.

MATERIALS AND METHODS

Experiments were conducted at CCS Haryana Agricultural University during 2012 and 2013 under the screen house conditions in the pots. The pot with a diameter of top and bottom 20.0 and 10.0 cm, respectively, and 20.0 cm height with soil carrying capacity of 4.7 kg were used in the study. Soil used for filling the pots was in the ratio of 3:1:1 with field soil, dunal sand and vermicompost. The field soil was sandy loam in texture and collected from fields where no herbicides were used for the last four years. Seeds were treated with 0.1% sodium hypochlorite immediately before each experiment for 30 minutes and washed 3-4 times with distilled water so as to ensure disease free seeds. Twenty seeds of four weed species, *viz. Echinochloa glabrescens, Leptochloa chinensis, Eragrostis japonica* and *Dactyloctenium aegyptium* were planted in each pot and watered regularly. Pendimethalin PE (0, 0.25, 0.5, 1.0, 2.0 kg/ha) was applied just after sowing of weed seeds with the help of a knapsack sprayer using water 300 L/ha with a flat fan nozzle. Herbicide dose was calculated on area basis and amount of water used in one hectare. Accordingly, concentration of herbicide was maintained in spray solution on the basis of herbicide rate. Cyhalofop-butyl + penoxsulam in ratio of 5:1 (0, 32.5, 65, 135, 270 g/ha) was applied 25 DAS similar to PE herbicide using a knapsack sprayer fitted with flat fan nozzles. Control pots were maintained for each herbicide and species for comparisons. Visual mortality (%) was recorded on a 0-100 scale, where 0 = no control and 100 = complete mortality) compared to untreated pots at 1, 2, and 4 weeks after treatment (WAT). Also, dry weight was also recorded at 4 WAT.

Due to similar trends, experimental data were pooled for both the years and analyzed using SPSS software version 7.5. The per cent data were subjected to arcsine transformation before statistically analysis. The experiment was asymmetrical factorial which was designed in CRD with four replications. The significant treatment effect was judged by using ‘F’ test at 5% level of significance.

RESULTS AND DISCUSSION

Pendimethalin

E. japonica proved the most robust, among all the four weed species, as it had lowest visual mortality, when averaged over different herbicide rates of pendimethalin at 4 WAT (**Table 1**). There was statistically significant difference in visual mortality by pendimethalin at all the stages. The visual mortality increased as the rates of pendimethalin increased and pendimethalin at the highest rate of 2000 g/ha provided complete kill of all the four species at all the stages of observations. At the lowest dose of pendimethalin (250 g/ha), *L. chinensis* showed maximum sensitivity among the test species.

There was statistically significant difference in visual mortality at 1 WAT, by pendimethalin when applied at 1000 and 2000 g/ha, data averaged over weed species and similar trends were recorded at 28 DAT. The results were supported by the findings of Koèárek *et al.* (2015) where it was recorded that half-life of pendimethalin ranged from 24.4 to 34.4 days, though pendimethalin can persists up to 240 days (Singh *et al.* 1994). There was complete mortality of *L. chinensis* and *D. aegyptium* at 1.0 and 2.0 kg/ha. Similar trends were recorded at 2 and 4 WAT, whereas *E. glabrescens* and *E. japonica* showed some tolerance at 1.0 kg/ha. Similar to these findings, Khaliq and Matloob (2012) also recorded the effectiveness of pendimethalin applied at 1137 g/ha in reducing the germination of *Echinochloa colona* in pot experiment. Whereas, Ahmed and Chauhan (2015) studied the effect of pendimethalin and found that increased rates of pendimethalin did not reduce total weed density; however, it reduced biomass of weeds significantly. When averaged over different weed species and herbicide rate, mortality percentage decreased from 80.1 to 76.2 as time increased from 1st to 2nd week, but this difference was narrowed as experiment advanced to 4th week. The difference in rate of growth could be due to faster metabolism of herbicide initially and later followed decreasing rate. There was no change in mortality percentage at 1.0 and 2.0 kg/ha when data averaged over different weed species. This could be attributed to the finding

Table 1. Effect of pendimethalin on periodical visual mortality (%) of rice weeds in pots

Weed Specie	Pendimethalin rate (g/ha)				Mean
	250	500	1000	2000	
1 WAT					
E. glabrescens	65.0 (53.7)	86.7 (68.7)	95.0 (77.1)	100.0 (90.0)	86.7 (72.4)
L. chinensis	73.3 (58.9)	90.0 (72.0)	100.0 (90.0)	100.0 (90.0)	90.8 (77.7)
E. japonica	30.0 (33.2)	48.3 (44.0)	93.3 (75.2)	100.0 (90.0)	67.9 (60.6)
D. aegyptium	38.3 (38.2)	61.7 (51.7)	100.0 (90.0)	100.0 (90.0)	75.0 (67.5)
Mean	51.7 (46.0)	71.7 (59.1)	97.1 (83.1)	100.0 (90.0)	80.1 (69.6)
LSD (p=0.05), weed species and pendimethalin rate = 1.9, interaction=3.9					
2 WAT					
E. glabrescens	30.0 (33.2)	65.0 (53.7)	95.0 (77.0)	100.0 (90.0)	72.5 (63.5)
L. chinensis	73.3 (59.0)	90.0 (72.0)	100.0 (90.0)	100.0 (90.0)	90.8 (77.8)
E. japonica	30.0 (33.2)	48.3 (44.0)	93.3 (75.2)	100.0 (90.0)	68.0 (60.7)
D. aegyptium	38.3 (38.2)	61.7 (51.7)	100.0 (90.0)	100.0 (90.0)	75.0 (67.5)
Mean	42.9 (40.9)	66.3 (55.4)	97.1 (83.1)	100.0 (90.0)	76.6 (67.4)
LSD (p=0.05), weed species and pendimethalin rate = 1.8, nteraction=3.8					
4 WAT					
E. glabrescens	30.0 (33.3)	45.0 (42.1)	95.0 (77.0)	100.0 (90.0)	67.5 (60.6)
L. chinensis	73.3 (59.0)	90.0 (72.0)	100.0 (90.0)	100.0 (90.0)	90.8 (77.8)
E. japonica	30.0 (33.2)	48.3 (44.0)	93.3 (75.2)	100.0 (90.0)	68.0 (60.7)
D. aegyptium	38.3 (38.2)	61.7 (51.7)	100.0 (90.0)	100.0 (90.0)	75.0 (67.5)
Mean	42.9 (40.9)	61.3 (52.5)	97.1 (83.1)	100.0 (90.0)	75.3 (66.7)
LSD (p=0.05), weed species and pendimethalin rate = 1.8, interaction=3.8					

Figures in parentheses are arcsine transformed

Table 2. Effect of pendimethalin on dry weight (g/pot) of rice weeds at 4 WAT

Weed species	Pendimethalin rate (g/ha)					Mean
	0	250	500	1000	2000	
E. glabrescens	2.90	2.50	2.10	0.20	0.00	1.54
L. chinensis	1.70	1.07	0.31	0.00	0.00	0.62
E. japonica	2.81	1.53	1.32	0.63	0.00	1.26
D. aegyptium	2.02	1.30	0.73	0.00	0.00	0.81
Mean	2.36	1.60	1.11	0.21	0.00	1.06
LSD (p=0.05), weed species=0.09, pendimethalin rate = 0.10, interaction=0.21						

of Koèárek *et al.* (2016), which concluded that double dose did not increase the pendimethalin half-life.

Pendimethalin sprayed at 2.0 kg/ha had zero dry weight for all weed species, whereas, *L. chinensis* and *D. aegyptium* even failed to emerge at pendimethalin 1.0 kg/ha and produced no biomass at these application rates (**Table 2**). When pendimethalin rate was increased from 0.25 to 0.5 kg/ha, there was 30% reduction in dry weight, but when it was increased from 0.50 to 1.0 kg/ha, it was 82% reduction in dry weight per pot. Data averaged over all weed species showed that lower rate may be metabolized fast and more than higher rate resulting in lower mortality, hence more reduction in dry matter. Averaging weed dry weight data across pendimethalin rates revealed that maximum dry weight per pot was recorded by *E. glabrescens,* which significantly differed to other weed species. There was 91% reduction in weeds dry weight per pot with pendimethalin 1.0 kg/ha application compared to control suggesting that this rate of pendimethalin can be used for managing these weeds in DSR.

Effect of cyhalofop-butyl + penoxsulam

At 1 WAT, cyhalofop-butyl+penoxsulam sprayed at 25 DAS had least control of *E. japonica* followed by *D. aegyptium* (**Table 3**). *L. chinensis* had the highest mortality percentage, when data was averaged over different rates of applications, indicating a good herbicide mixture for managing fields dominated by this weed. Earlier researchers (Jacob *et al.* 2017) have also reported that cyhalofop-butyl provided 96% control of *L. chinensis* but penoxsulam gave only 35% control. In this study, cyhalofop-butyl + penoxulam applied at 270 g/ha resulted in highest control of *L. chinensis* (88.3%) compared to other weed species as recorded after

Table 3. Effect of cyhalofop-butyl + penoxsulam (5:1) on periodical percent visual mortality of rice weeds in pots

Weed Species	Cyhalofop-butyl + penoxsulam (g/ha)				Mean
	32.5	65	135	270	
1 WAT					
E. glabrescens	20.0 (26.6)	40.0 (39.2)	41.7 (40.2)	81.7 (64.7)	45.8 (42.7)
L. chinensis	38.3 (38.2)	43.3 (41.2)	46.7 (43.1)	88.3 (70.1)	54.2 (48.1)
E. japonica	11.7 (19.9)	13.3 (21.3)	33.3 (35.2)	36.7 (37.3)	23.8 (28.4)
D. aegyptium	21.7 (27.7)	25.0 (30.0)	43.3 (41.2)	46.7 (43.1)	34.2 (35.5)
Mean	22.9 (29.3)	30.4 (32.2)	41.2 (39.4)	63.4 (53.8)	39.5 (38.7)
LSD (p=0.05), weed species and cyhalofop-butyl + penoxsulam = 1.5, interaction= 2.9					
2 WAT					
E. glabrescens	25.0 (30.0)	60.0 (50.8)	86.7 (68.7)	100.0 (90.0)	67.9 (59.9)
L. chinensis	63.3 (52.7)	78.3 (62.3)	91.7 (73.4)	100.0 (90.0)	83.3 (69.6)
E. japonica	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0(0.0)	0.0 (0.0)
D. aegyptium	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	20.0 (26.6)	5.0 (6.6)
Mean	22.0 (23.1)	34.6 (25.9)	44.6 (35.5)	55.0 (51.6)	39.1 (34.0)
LSD (p=0.05), weed species and cyhalofop-butyl + penoxsulam = 1.0, interaction=2.0					
4 WAT					
E. glabrescens	33.3 (35.2)	63.3 (52.7)	95.0 (77.1)	100.0 (90.0)	72.9 (63.8)
L. chinensis	83.3 (65.9)	90.0 (71.6)	98.3 (85.7)	100.0 (90.0)	92.9 (78.3)
E. japonica	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
D. aegyptium	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	20.0 (26.6)	5.0 (6.6)
Mean	29.2 (35.2)	38.3 (52.7)	48.3 (77.1)	55.0 (51.6)	42.7 (63.8)
LSD (p=0.05), weed species and cyhalofop-butyl + penoxsulam = 1.7, interaction=3.3					

Figures in parentheses are arcsine transformed

Table 4. Effect of cyhalofop-butyl + penoxsulam (5:1) on dry weight (g/pot) of rice weeds at 4 WAT

Weed species	cyhalofop-butyl + penoxsulam (g/ha)					Mean
	0.0	32.5	65	135	270	
E. glabrescens	4.54	2.93	1.39	0.50	0.00	1.87
L. chinensis	2.41	0.84	0.41	0.34	0.00	0.80
E. japonica	4.13	3.60	2.34	2.32	2.23	2.92
D. aegyptium	4.80	4.24	3.58	2.97	2.23	3.56
Mean	3.97	2.90	1.93	1.53	1.11	2.29
LSD (p=0.05), weed species=0.10 and cyhalofop-butyl + penoxsulam = 0.11, interaction=0.23						

one week of herbicide application. Initially, the difference in visual mortality of *L. chinensis* between 135 g/ha and 270 g/ha application rate was prominent but as time advanced it was narrowed down. At 1 WAT, *E. japonica* recorded significantly lowest visual control (11.7%), when cyhalofop + penoxulam applied at 32.5 g/ha, which was statistically at par with cyhalofop-butyl + penoxsulam at 65 g/ha. Whereas, no visual mortality of *E. japonica* was recorded at 2 and 4 WAT at any of the application rate. *D. aegyptium* was not effectively controlled by cyhalofop-butyl + penoxsulam as there was only 20% control at 4 WAT when applied at 270 g/ha. Although, at 1 WAT, there was 22-47% visual phytotoxicity at different application rates. *L. chinensis* and *E. glabrescens* had higher visual phytotoxicity and it further increased with time, when data were averaged over different rate of cyhalofop-butyl + penoxsulam. Similar to present findings, Lap *et al.* (2013) and Singh (2016) reported that cyhalofop-butyl + penoxsulam mixture is highly effective in controlling *Echinochloa* spp. based on the different trials conducted across Asia.

As there was less effect of herbicide mixture on E. *japonica* and *D. aegyptium*, higher dry weight/pot was recorded in both the species, when data were averaged over different herbicide rates (**Table 4**). There was significant decrease in dry weights with increase in herbicide rates. Dry weight reduction of 35% in *E. japonica* was recorded as cyhalofop-butyl + penoxsulam rate doubled from 32.5 to 65 g/ha, but further doubling the rate resulted in a further decrease of only 5% dry weight. At the highest application rate, no dry weight was recorded of *E. glabrescens* and *L. chinensis* as both showed 100% mortality. Yao *et al*. (2013) also found cyhalofop-butyl + penoxsulam excellent in controlling *E. glabrescens* and *L. chinensis* at different locations in China. Compared to untreated control, the highest rate of cyhalofop-butyl + penoxsulam reduced the dry weight of *E. japonica* and *D. aegyptium* by 46 and 54%, respectively. When averaged over different weed species, the mean dry weights were significantly different among various herbicide rates and 72% reduction in dry weight was recorded with the highest application rate of cyhalofop-butyl + penoxsulam when compared with untreated control.

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Mechanized weed management to enhance productivity and profitability in system of rice intensification

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ABSTRACT

An experiment was conducted during 3 consecutive rainy seasons of 2015 to 2017 at ICAR-Research Complex for Eastern Region, Patna to evaluate the mechanized weed management practices for enhancing the productivity in system of rice intensification (SRI) against farmers' practice. The seven weed management treatments, *viz.* conoweeder thrice at 15, 25 and 35 DAT, conoweeder twice at 15 and 30 DAT, post-emergence (PoE) application of bispyribac-Na 25 g/ha (20 DAT) + conoweeder at 35 DAT, conoweeder 15 DAT + bispyribac-Na 25 g/ha (20 DAT), conoweeder on 15 DAT + bispyribac-Na 25 g/ha (20 DAT) + conoweeder 35 DAT, unweeded check and farmers' practice were evaluated under randomized block design with three replications. *Fimbristylis miliacea* was the top ranking weed with the highest degree of weed infestation. Significantly the highest grain yield (5.97 t/ha) was obtained from 3 times conoweeder at 15, 25 and 35 DAT, which was at par with conoweeder twice on 15 and 30 DAT (5.40 t/ha). Integration of herbicide with mechanical weeder did not improve the weed control efficiency and grain yield over conoweeder twice on 15 and 30 DAT. The highest weed control efficiency of 93.3 and 91.7% at 60 DAT were obtained with application of conoweeder thrice at 15, 25 and 35 DAT and conoweeder twice at 15 and 30 DAT, respectively. The crop raised by SRI method produced significantly higher grain and straw yields than that of farmers' practice except unweeded check under SRI, which was heavily infested with weeds (weed density 153.27/m^2 and weed biomass 129.93 g/m^2). However, in SRI, 2 times conoweeder at 15 and 30 DAT, was found to be effective and economical leading to cost saving for the farmers.

INTRODUCTION

The system of rice intensification (SRI) is a methodology aimed at increasing the yield of rice through effective integration of crop, soil, water and nutrient management (Uphoff 2003). It is a low water and labour intensive method that uses younger seedlings singly spaced and typically hand weeded with special tools under wide planting geometry. Water productivity increased by 61.8% in check basin irrigated SRI as compared to water productivity of 0.34 kg/m^3 in farmers' method of rice establishment (Kumar *et al.* 2015). Under SRI, weeds grow more vigorously, and need to be kept under control at an early stage. A rotary hoe or conoweeder is used starting at 15 days after transplanting (DAT), repeated ideally every 10 days until the canopy is closed. Use of mechanical weeders breaks up the surface soil as it turns weeds into mulch, stimulates root growth by root pruning and conserving their nutrients as they decompose in the soil. The use of the weeder contributes to homogeneous field conditions, creating a uniform crop stand and leading to increased yields. This practice, especially if done several times, can add 1 to 3 t/ha to yield without other soil amendments, by inducing better soil health and more nutrient cycling and solubilization through microbial activity (Singh 2018). On the other hand, chemical methods lead to environmental pollution and in many weed species developed resistance against herbicides. In view of the increasing labour scarcity and negative impact of indiscriminate herbicides use, weed management strategy needs to be reoriented towards mechanical means for satisfactory monetary benefits. The present study was undertaken to study the effect of different weed management options in SRI and their effects on yield attributes, grain yield and economics.

MATERIALS AND METHODS

Field experiments were conducted during 3 consecutive rainy seasons of 2015 to 2017 at ICAR-Research Complex for Eastern Region, Patna (25º 37'

N, 85º 13’ E and 53 m above mean sea level). The soil was silty clay loam (55.6% sand, 15.5% silt and 28.9% clay) in texture, neutral in reaction (pH 6.6 in 1: 2.5 soil: water), having 250 kg/ha available N, 10.5 kg/ha Olsen’s P and 250 kg/ha extractable K. The top 15 cm soil had bulk density of 1.5 g/cm^3, field capacity 35% and permanent wilting point of 15.5% on oven-dry basis. Seed of rice variety ‘*Arize 6444*’ was treated with *Trichoderma viride at* 5 g/kg seed. On the same day, seeds were sown in nursery bed for SRI (in raised bed, germinated seeds were spread and covered with well rotten dry FYM to facilitate transplanting of younger seedlings) and farmers’ method (in well puddled nursery bed in densely spread out germinated seeds). Twelve days old seedlings were transplanted singly for SRI in well puddled, clean and moist plots measuring 6 x 4 m at 25 x 25 cm hill spacing on 16 July, 6 August and 14 August, receiving total rainfall of 296.9, 554.7 and 199.7 mm during crop period of 2015, 2016 and 2017, respectively.

In all the SRI planted plots irrigation was applied so as to maintain saturation all throughout. Whereas, in farmers’ practice, 21 days old seedlings were transplanted on the same dates as in the case of SRI during all the three years maintaining 20 x 15 cm hill spacing in well puddled 6 x 4 m plots with 2-3 seedlings/hill. In farmers’ practice, crop was managed with inorganic fertilization, flooded irrigation and one hand weeding at 25-30 DAT. The seven weed management treatments, *viz.* conoweeder thrice at 15, 25 and 35 DAT, conoweeder twice at 15 and 30 DAT, post-emergence (PoE) application of bispyribac-Na 25 g/ha (20 DAT) + conoweeder at 35 DAT, conoweeder 15 DAT + bispyribac-Na 25g/ha (20 DAT), conoweeder on 15 DAT + bispyribac-Na 25 g/ha (20 DAT) + conoweeder 35 DAT, unweeded check and farmers’ practice were evaluated under randomized block design with three replications.

In SRI plots, half of the recommended dose of N (50 kg/ha) through vermicompost and full dose of P_2O_5 and K_2O 60 and 40 kg/ha, respectively were given through single super phosphate and muriate of potash before transplanting at final land preparation and remaining N (50 kg/ha) was top-dressed in 2 equal splits (half at active tillering and the rest half at panicle initiation stage).

The crop was harvested on 10 November, 1 December and 7 December during 2015, 2016 and 2017, respectively and the farmers method planted plots were harvested about 10 -12 days before SRI. Observations on weed counts (no./m^2) and weed dry weight (g/m^2) were taken by sampling randomly at 4 places with the help of 0.25 m^2 quadrates at 40 and 60 DAT and the data were transformed using $\sqrt{x+0.5}$ before statistical analysis. Weed control efficiency $[WCE = \{(WC - Wt)/WC\} * 100]$ was also calculated. Panicle numbers were recorded on the day of crop harvest based on randomly selected 10 panicles/hills of each plot, filled grains/panicle were recorded at 2-3 days after crop harvest based on randomly selected ten panicles. Test weight of grains was computed by taking 1000-bold seeds from each plot after proper sun-drying. The statistical analysis was done with the standard statistical method (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

Effect on weeds

Nine different weed species were found to infest the experimental crop. The most important weed species in the experimental plots throughout the growing period were *Fimbristylis miliacea*, *Echinochloa crus-galli, Eleusine indica*, *Leptochloa chinensis* and *Cynodon dactylon*. At 40 DAT, *Fimbristylis miliacea* was the top ranking weed with the highest degree of weed infestation (**Table 1**) followed by *Echinochloa crus-galli* and *Eleusine indica*. Further at 60 DAT, four new weed species emerged and *Fimbristylis miliacea* followed by *Echinochloa crus-galli* maintained their superiority in terms of degree of infestation over other weeds (**Table 1**).

Table 1. Degree of weed infestation in experimental field at different stages (pooled mean of 3 years)

Weed species	Degree of weed infestation (%)	
	40 DAT	60 DAT
Echinochloa crus-galli	16.21	20.96
Cyperus rotundus	0	5.13
Cyperus iria	0	10.74
Cyperus difformis	0	12.21
Cynodon dactylon	2.74	3.32
Fimbristylis miliacea	63.65	35.91
Ludwigia parviflora	0	1.31
Leptochloa chinensis	4.13	4.30
Eleusine indica	13.27	6.12

The highest weed density (153.3/m^2) and weed biomass (129.93 g/m^2) were found in the unweeded treatment at 60 DAT, which was significantly higher than in other treatments (**Table 2**). Similar results were also reported by Mandal *et al.* (2013) and Mitra *et al.* (2005). Farmers’ practice resulted inthe second highest weed density and weed biomass at 40 and 60 DAT, which were significantly higher than other treatments. Mechanical weeding by conoweeder at 15, 25 and 35 DAT followed by conoweeder at 15 and 30 DAT were most effective than the other treatments in controlling the weeds up to 60 DAT (**Table 2**). SRI with conoweeding four times at 10 days interval resulted in significantly lower weed biomass (Uprety 2010). Row weeding machine can be run in SRI fields up to 30 DAT because profuse lateral vegetative growth of rice is vulnerable to the damage by the row weeding (Haden 2007). Moreover, weeders fail to remove all the weeds growing in intra-row spaces, which compete with rice plants; even some of the weeds are able to re-grow from their roots, particularly, rhizomatous, weeds, sedges, *etc*. (IRRI 2014).

Effect on rice

Weed management treatments had the significant effect on production of number of panicle/m^2 and grains/panicle. The highest number of panicle and number of grains/panicle were obtained in conoweeder at 15, 25 and 35 DAT followed by conoweeder at 15 and 30 DAT (**Table 3**). It might be due to the least crop-weed competition that ensured sufficient nutrients and other growth resources, which enhanced higher grains/panicle production. Roy (2012) also reported that three times mechanical weeding in both direction was capable to produce higher yields. 1000-grain weight was also influenced by weed control treatments, but the variation was not significant. It might be due to that grain size is a genetically controlled character and influenced little by management practices. Grain yield was also significantly affected by weed control treatments (**Table 3**). The significantly highest grain yield (5.97 t/ha) was obtained from 3 times conoweeder at 15, 25 and 35 DAT among all treatments except with conoweeder twice on 15 and 30 DAT (5.40 t/ha). Integration of herbicide in weed management treatments, *viz*. conoweeder 15 DAT + bispyribac-Na as PoE 25 g/ha (20 DAT) + conoweeder 35 DAT, Conoweeder15 DAT + bispyribac-Na as PoE 25 g/ha (20 DAT) and PoE application of bispyribac-Na 25 g/ha (20 DAT) + conoweeder use 35 DAT failed to improve weed control efficiency over conoweeder twice on 15 and 30 DAT. The highest weed control efficiency of 93.3 and 91.7% up to 60 DAT (**Table 2**) were obtained in treatments of conoweeder thrice at 15, 25 and 35 DAT and conoweeder twice at 15 and 30 DAT, respectively. The results corroborate the findings of Mohapatra *et al.* (2012). The use of conoweeder caused 10-17% increase in grain yield during wet season (Mandal *et al.* 2013). Higher numbers of conoweeding effectively buries and incorporates the weeds into soil and minimizes the weed competition. Further it improves the soil aeration, root development, nutrient absorption and more number of tillers, which favoured the crop growth, yield attributes and resulted in higher grain

Table 2. Effect of weed management treatments on weed density, dry weight and weed control efficiency (pooled mean of three years)

Treatment	Weed density (no./m^2)		Weed dry biomass (g/m^2)		Weed control efficiency (%)	
	40 DAT	60 DAT	40 DAT	60 DAT	40 DAT	60 DAT
Conoweeder thrice on 15, 25, and 35 DAT	6.06(36.8)	5.21(27.0)	2.59(6.3)	3.04 (8.8)	67.36	93.3
Conoweeder twice on 15 and 30 DAT	7.34 (53.6)	6.29(39.3)	2.81(7.5)	3.36 (10.8)	61.14	91.7
Bispyribac-Na as PoE 25 g/ha (20 DAT) + conoweeder use 35 DAT	6.77 (45.3)	5.84(33.6)	2.95(8.3)	4.13(16.5)	56.99	87.3
Conoweeder 15 DAT + bispyribac-Na as PoE 25 g/ha (20 DAT)	6.84(46.8)	5.88(34.3)	3.33(10.7)	4.19(17.0)	44.56	86.9
Conoweeder on 15 DAT + bispyribac-Na as PoE 25 g/ha (20 DAT) + conoweeder on 35 DAT	6.67(44.2)	5.71(32.4)	2.93(8.2)	4.24(17.5)	57.51	86.6
Unweeded check	14.13(200.4)	12.36(153.3)	8.54(73.4)	11.42(129.9)	0	0
Farmers' practice	9.73(94.5)	8.29(69.3)	3.7(13.3)	5.05 (25.0)	31.09	80.8
LSD (p=0.05)	1.25	1.59	0.79	0.94	-	-

Values in parentheses are original means

Table 3. Effect of weed management treatments on yield attributes, grain yield of rainy season planted SRI (pooled mean of three years)

Treatment	Panicle no./m^2	No. of grains/ panicle	1000-grain weight (g)	Straw yield (t/ha)	Rice grain yield (t/ha)			
					2015	2016	2017	Mean
Conoweeder thrice on 15, 25, and 35 DAT	253	96	22.33	6.56	6.35	6.15	5.41	5.97
Conoweeder twice on 15 and 30 DAT	225	93	21.00	5.96	6.20	6.00	4.00	5.40
Bispyribac-Na as PoE 25 g/ha (20 DAT) + conoweeder use 35 DAT	194	89	21.00	5.6 1	5.80	5.35	3.76	4.97
Conoweeder 15 DAT + bispyribac-Na as PoE 25 g/ha (20 DAT)	195	90	21.66	5.76	5.95	5.45	3.60	5.00
Conoweeder on 15 DAT + bispyribac-Na as PoE 25 g/ha (20 DAT) + conoweeder on 35 DAT	196	90	22.33	5.78	6.15	5.80	3.14	5.02
Unweeded check	135	71	19.33	3.50	3.20	3.00	2.20	2.80
Farmers' practice	161	80	20.00	4.37	3.65	3.25	3.18	3.36
LSD (p=0.05)	27	10	NS	1.24	0.77	0.82	1.14	0.91

Table 4. Effect of weed management treatments on economics of rainy season planted SRI (pooled mean of three years)

Treatment	Economics			
	Gross return ($x10^3$ `/ha)	Cost of cultivation ($x10^3$ `/ha)	Net return ($x 10^3$ `/ha)	Benefit : cost ratio
Conoweeder thrice on 15, 25, and 35 DAT	92.53	70.62	21.91	1.31
Conoweeder twice on 15 and 30 DAT	91.14	66.62	24.52	1.37
Bispyribac-Na as PoE 25 g/ha (20 DAT) + conoweeder use 35 DAT	84.04	64.62	19.42	1.30
Conoweeder 15 DAT + bispyribac-Na as PoE 25 g/ha (20 DAT)	84.70	64.00	20.70	1.32
Conoweeder on 15 DAT + bispyribac-Na as PoE 25 g/ha (20 DAT) + conoweeder on 35 DAT	85.03	64.00	21.03	1.32
Unweeded check	47.77	46.00	1.77	1.04
Farmers' practice	57.54	56.50	1.04	1.02

Sale price of paddy is ` 15500/t and Straw: ` 1250/t

yield (**Table 3**). The SRI yield reduction due to weed competition could be up to 69.15% (Babar and Velayutham 2012). The crop raised by SRI method produced significantly higher grain and straw yield than plots planted under farmers' practice except unweeded check under SRI, which was heavily infested with weeds (**Table 2**). Regarding economics, the higher yielding treatments recorded higher net returns and benefit: cost ratio (**Table 4**). Conoweeder further reduced man-days required for weeding from 30 to 10 (Mrunalini and Ganesh 2008), thus helped saving labour and time. In lowland *(tarai)* belt of Uttarakhand, a decrease in cost of cultivation by ` 1,000/ha mainly due to less cost involved in transplanting of rice seedlings and 5% increase in grain yield increased net returns by over ` 3,000/ha under wider spacing (25 x 25 cm) compared to closer spacing of 20 x 20 cm (Dass and Chandra 2012).

It may be concluded that weed management through conoweeder twice at 15 and 30 DAT has been found most effective and economical in SRI method of rice establishment.

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Weed management in transplanted rice with special reference to *Commelina benghalensis* in the Kymore Plateau Satpura hills region of Madhya Pradesh

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ABSTRACT

During 2014-17, an on-farm research trial was conducted at five farmer fields in Katni district of Madhya Pradesh to validate, refine and popularize the technology for managing *Commelina benghalensis* L. The study aimed to find out the efficacy of bispyribac-sodium 20 g/ha, pyrazosulfuron 20 g/ha and pendimethalin 1.5 kg/ha over farmers practice (hand weeding twice at 30 and 60 DAT) and unweeded control on the management of weeds and profitability of rice (*Oryza sativa*) sown in transplanted condition. Bispyribac-sodium 20 g/ha at 20-21 DAT reduced the density of *C. benghalensis* upto 9.8 no./m^2 and dry weight upto 6.9 g/m^2 and also reduced the infestation of other weeds to a significant extent. Higher values of yield attributes such as number of panicles (229/m^2), grain yield (3.46 t/ha) and net returns (` 31820/ha), as well as less values of nutrient uptake by weeds (5.8 kg N, 1.1 kg P and 6.9 kg K/ha) were recorded with this herbicide compared to farmers practice.

INTRODUCTION

Weeds are considered as the more harmful than insects, fungi or other crop pests in many situations as far as economic loss is concerned. Among all biotic constraints, they cause more harm to agricultural production besides affecting agro biodiversity and natural aquatic bodies. They also have a negative effect on the crop production indirectly by competing with the crop plants for inputs, providing shelter to crop pests, negatively affecting water management, reducing the yield and quality of produce, and subsequently increasing the cost of processing (Zimdahl 2013). In a recent study, total actual economic loss due to weeds alone in 10 major field crops of India was estimated as USD 11 billion (Gharde *et al*. 2018a and b).

Rice is the most widely cultivated rainy season's cereal in Madhya Pradesh. Owing to favourable weather and soil moisture regime, *Commelina* spp. infestation is a major biotic constraint to rainy rice production. In the Kymore Plateau Satpura hills region of Katni district of Madhya Pradesh, four species of *Commelina*, notably *C. communis* L., *C. diffusa* Burm., *C. elegans* Kunth. and *C. benghalensis* L. as well as their biotypes are present. They are perennial herbs and considered as important problem in prevalent cropping systems where they have become continual and become difficult to control. *Commelina benghalensis* is the most important among four and it occurs as a major weed in 25 different crops in 28 countries (Holm *et al.* 1977). *C. benghalensis* has been found infesting different field crops during rainy season especially rice fields. Season-long infestation of this weed alone causes grain yield reduction by 13-40% and removes considerable amount of soil nutrients (Shukla *et al.* 2014).

Therefore, present investigation was conducted at selected farmers' fields with the objective to validate, assess and refine the technology, to test its sustainability and energy-use efficiency over traditional farmers practice in terms of growth, yield and economics of rice as influenced by various herbicides.

MATERIALS AND METHODS

Commelina spp, a serious constraint in the Kymore Plateau Satpura Hills Region of Katni district of Madhya Pradesh, causes poor rice yield and high cost of production due to its heavy infestation. Therefore, replicated on-farm trials were conducted at five farmers fields in five villages (similar agro-climatic conditions) namely Deori (23^{0}89'N 80^{0}29'E), Umariyapan (23^{0}50'N 80^{0}27'E), Banda (23^{0}68'N 80^{0}34'E), Lakhapateri (23^{0}69'N 80^{0}32'E) and Dhundhari (23^{0}73'N 80^{0}30'E) of Katni district of

Madhya Pradesh during 2014-17 and means were used for further interpretation. The soil of the sites was sandy loam to silt clay loam, acidic in pH and medium in available N (385 kg/ha), P (14.7 kg/ha) and high in K (308 kg/ha). The bulk density of the soil was 1.25 Mg/m^3. The experiment comprised of five treatments, *viz*. bispyribac-sodium 20 g/ha, pyrazosulfuron 20 g/ha as post-emergence and pendimethalin 1.5 kg/ha as pre-emergence, farmers practice (hand weeding twice at 30 and 60 DAT) and unweeded control. These were laid out in a randomized block design at each farmer's field. Rice '*MTU 1010*' was sown by transplanting (SRI) at seed rate of 20 kg seed/ha during second fortnight of July in all the three years. The crop was fertilized with 15 t/ha of well decomposed FYM only.

Herbicides were applied with a manually operated knapsack sprayer delivering a spray volume of 500 litres/ha through flat-fan nozzle. Data on weed density and dry weight were recorded at 70-90 days after sowing in each plot in two quadrates, each of 1 x 1m. Species–wise, weeds were counted and removed for recording their dry weight. Crop was manually harvested on first fortnight of October in all the years. The grain yield data were recorded and adjusted to 14% of the moisture content. Data on weed count were subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis. Data were analyzed using ANOVA, and the least significant difference (LSD) values at 5% level of significance were calculated and used to test significant difference between treatment means. At harvest, grain and straw samples of rice were collected and analyzed for total N using a micro-Kjeldahl method, whereas total P and K were determined using sulphuric-nitric perchloric acid digest as suggested in Prasad and Rafey (1995). Nutrient removal was obtained by multiplying the N, P and K concentration (%) of grain and straw with their respective yield (kg/ha) and ultimately the nutrient uptake by grain and straw was sum up in order to obtain total nutrient uptake. Nutrient harvest index was computed using the formula given below:

$$\text{Nutrient harvest index} = \frac{\text{Uptake of a particular nutrient by the grain}}{\text{Total uptake of that nutrient in biomass}}$$

The weed index was calculated by using the following formula (Gill and Kumar 1969).

$$WI = \frac{YWF - Yt}{YWF} \times 100$$

where, WI = Weed index, YWF = Average yield of crop in weed free plot, Yt = Average yield of crop in treated plot.

Weed control efficiency (WCE) was calculated by using following formula (Mani *et al*. 1973 and Das 2008):

$$WCE(\%) = \frac{WP_U - WP_T}{WP_U} \times 100$$

where, WP_U is the weed population (no./m^2) in unweeded plot and WP_T is the weed population (no./m^2) in treated plot.

The post-harvest soil samples were collected from 0-20 cm depth in the fields for analyzing available nutrient status and analysed for their respective dry weights across treatments. Treatment-wise data were computed using the prevailing market price of inputs such as bispyribac-sodium ` 5800/- per litre, pyrazosulfuron ` 1000/- per kg and pendimethalin ` 600/- per litre, labour wages ` 164/ man-day and outputs, *viz*. rice foundation seeds ` 27/ kg and straw ` 4/kg. Economics were calculated based on the prevailing market price of the input and produce. Energy balance was computed based on the equivalent values of input and output in energy terms (MJ/ha) as per Mittal *et al*. (1985).

RESULTS AND DISCUSSION

Effect on weeds

The weed flora recorded from the unweeded control plots consisted of *Commelina* spp. (71%) and others (29%) as *Echinochloa crus-galli*, *E. colona, Cyperus iria*, *Eclipta alba*, *Fimbristylis* sp. and *Marsilea quadrifolia*. All herbicidal treatments significantly reduced population of weed compared to farmers' practice (**Table 1**). It was mainly because of effective weed control during early stages of crop growth. In farmers' practice (hand weeding twice at 30 and 60 DAT), weeds particularly *Commelina* were not controlled due to its deep-tap root system and faster regrowth soon after weeding as well as cutting also having capacity to reproduce self. Application of bispyribac-sodium being at par with pyrazosulfuron and pendimethalin spray significantly reduced weed density and dry weight of total weeds compared to other treatments and resulted in the highest weed control efficiency (93.8%). Similarly, spray of pyrazosulfuron 20 g/ha resulted in the lowest weed index (3.2) in comparison to other treatments. Dry weight of *C. benghalensis* was remained at par with all herbicidal treatments while it was significantly lesser with application of bispyribac sodium over farmers' practice. Total weed dry weight was significantly less with all herbicidal treatments in comparison to farmers' practice, however, individual application of bispyribac-sodium behaved similarly in terms of weed population and biomass. Shukla *et al.* (2014) also observed the same results in similar agro-climatic conditions.

Effect on rice

Lesser weed-crop competition due to effective control of weeds (**Table 2**) in all herbicidal treatments resulted in significant improvement in crop growth, yield attributes and grain yield of rice in comparison to farmers' practice due to spray of bispyribac sodium which managed both broad-leaved weeds as well as other weeds. Among herbicidal treatments, application of bispyribac produced significantly higher panicles/m^2 of rice over other herbicidal treatments due to lesser crop-weed competition (Singh *et al.* 2013).

In **Table 2**, year-wise yield data is presented with different treatment applications. Results from **Table 4** indicated that among all herbicidal treatments, bispyribac-Na 20 g/ha reported highest grain yield among all other treatments. However, there were no significant difference between pyrazosulfuron 20 g/ha and bispyribac-Na 20 g/ha in all the years. Further, application of bispyribac-Na 20 g/ha produced the highest yield attributes among all herbicidal treatments which concurrently recorded the highest average grain yield of rice (65% higher over farmers' practice). Grain yield of rice had a significant negative correlation (0.51 to 0.99) with weed parameters such as total weed population/m^2, total dry matter production (DMP) of weeds and N removal by the weeds, as well as a positive linear correlation with rice DMP and N uptake (0.97 and 0.39) (**Table 4**). Data on straw yield also showed same trend. Further, association between weeds, yield parameters and grain yield was also confirmed through correlation as given by Shukla *et al.* (2014).

Economic returns

Due to higher crop yields and low cost of herbicides application over farmers' practice of expensive manual weeding, all herbicidal treatments produced higher net returns and B: C ratio (**Table 2**). Application of bispyribac-Na produced higher net returns (` 31820/ha) and B:C ratio (3.15) which was ` 15500/-and 1.56, respectively in farmers' practice. This was mainly due to higher cost of cultivation due to high cost involved in hand weeding and poor grain yield in farmers' practice. These findings are in confirmation with the findings of Singh *et al.* (2013).

Nutrient uptake by weeds and rice

Unweeded control recorded the highest N, P and K by weeds (**Table 3**) mainly because of higher dry matter accumulation by weeds which enabled them to absorb more nutrients in this treatment. Application of bispyribac-sodium recorded significantly the lowest N, P and K uptake by weeds over other treatments due to efficient control of weeds. Similar results were also reported by Kolo and Umaru (2012). Similarly,

Table 1. Effect of different weed control treatments on density and dry weight of weeds, weed control efficiency and weed index in rice at 90 DAS (mean data of five farmers' fields)

Treatment	Weed density (no./m^2)			Dry weight of weed (g/m^2)			Weed control efficiency (%)	Weed index (%)
	Commelina benghalensis	Others	Total	*Commelina benghalensis*	Others	Total		
Pendimethalin 1.5 kg/ha as PE	4.7(21.4)	3.9(14.9)	6.1(36.4)	3.5(12.1)	3.8(13.9)	5.1(26.0)	78.8	7.9
Bispyribac-sodium 20 g/ha PoE	3.2(9.8)	2.2(4.3)	3.8(14.1)	2.7(6.9)	2.1(4.1)	3.4(11.0)	93.8	-
Pyrazosulfuron 20 g/ha as PoE	3.4(11.1)	3.3(10.3)	4.7(21.4)	3.4(10.8)	3.1(9.0)	4.5(19.8)	89.9	3.2
Unweeded control	8.5(71.4)	5.4(29.2)	10.0(10.6)	10.0(99.7)	5.4(28.8)	11.3(128.4)	-	27.8
Two hand weedings at 30 and 60 DAT	8.5(72.6)	5.9(34.7)	10.4(107.3)	4.7(21.6)	5.9(34.1)	7.5(55.7)	59.7	17.7
LSD (p=0.05)	1.41	1.23	2.1	1.75	1.58	1.39	-	-

*Figures in parentheses are original values; data were transformed through ($\sqrt{x+0.5}$); PE = Pre-emergence; PoE = Post-emergence

Table 2. Effect of weed control treatments on yield attributes, grain yield and economics of rice

Treatment	Panicles/ m^2	Grains/ panicle	1000-grain weight (g)	Grain yield (t/ha)				Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio
				2014-15	2015-16	2016-17	Average grain yield			
Pendimethalin 1.5 kg/ha as PE	178	58.71	25.01	2.21	2.09	2.39	2.23	47.99	25.90	2.25
Bispyribac-sodium 20 g/ha as PoE	229	76.8	32.12	3.49	3.61	3.27	3.46	58.82	31.82	3.15
Pyrazosulfuron 20 g/ha as PoE	201	65.43	29.82	3.16	3.00	3.2	3.12	53.04	26.54	2.31
Unweeded control	140	42.10	17.22	1.08	1.07	1.19	1.11	32.47	10.42	1.26
Two hand weedings at 30 & 60 DAT	152	50.21	21.09	2.01	1.98	2.3	2.10	37.59	15.50	1.56
LSD (p=0.05)	89	10.2	8	0.88	0.95	0.99	0.94	-	-	-

PE = Pre-emergence; PoE = Post-emergence

Table 3. Effect of different weed control treatments in rice on nutrient uptake by weeds and rice (mean data of three years)

Treatment	Nutrient uptake by weeds (kg/ha)			Nutrient uptake by rice (kg/ha)		
Pendimethalin 1.5 kg/ha as pre-emergence	8.2	1.9	10.2	55.7	9.6	47.8
Bispyribac-sodium 20 g/ha post-emergence	5.8	1.1	6.9	65.9	10.8	54.9
Pyrazosulfuron 20 g/ha as post-emergence	7.6	1.6	9.7	61.3	10.2	52.1
Unweeded control	15.2	2.8	24.4	51.4	9.1	41.8
Two hand weedings at 30 and 60 DAT	12.8	2.3	18.3	53.1	9.3	43.2
LSD (p=0.05)	3.1	0.7	2.4	8.2	0.9	5.9

Table 4. Correlation between grain yield and weed parameters in rice (mean data of three years)

y	x	Correlation coefficient (r) (n=25)
Grain yield (kg/ha)	Total weed population/m^2	-0.51*
Grain yield (kg/ha)	Total weed DMP (g/m^2)	-0.85**
Grain yield (kg/ha)	N removal by weed (kg/ha)	-0.99**
Grain yield (kg/ha)	Rice DMP (g/m^2)	0.97**
Grain yield (kg/ha)	N uptake by rice (kg/ha)	0.39

DMP: Dry matter production; *Significant at 5% level of significance; **Significant at 1% level of significance

N, P and K uptake by rice (grain and straw) were significantly higher in treatment involving application of bispyribac over farmers' practice because of greater weed control due to their lower density and dry weight of weeds and higher grain and straw yields (**Table 3**). The lower N, P and K uptake by weeds allowed rice to grow more vigorously and accumulate more dry matter, which consequently led to higher uptake of these nutrients. Kolo and Umaru (2012) also reported that N uptake by grain and straw was inversely proportional to the nutrient depletion by weeds supports our finding on nutrient uptake by rice and weeds. It can be concluded from present investigation that *C. benghalensis* and other associated weeds of transplanted rice in the Kymore Plateau Satpura Hills Region of Katni district of Madhya Pradesh conditions can be effectively managed with the spray of bispyribac-sodium (20 g/ha) at 20-21 DAT.

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Long-term effects of green manuring and herbicides on weeds and productivity of the rice-wheat cropping system in North-Western India

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ABSTRACT

A long-term field experiment from 1999-2000 to 2015-16 at CCS Haryana Agricultural University, Regional Research Station, Karnal, Haryana, India was done to study the effect of green manuring and continuous or rotational use of herbicides on weeds and productivity of the rice-wheat cropping system. Based on data from 2008-09 onward, the density of grassy weeds in the weedy plots under green manuring (GM) (7-37 plants/m^2) remained lower or equal to treatments without green manuring (WGM) (6-37 plants/m^2) in rice with few exceptions. Similarly, broad-leaf weeds (BLW) and sedges under GM (0-83 plants/m^2) remained lower or similar to WGM (0-106 plants/m^2) across different years. In wheat, the density of *Phalaris minor* was higher or similar under GM (55-229 plants/m^2) than WGM (45-177 plants/m^2), while the converse was true for BLW (19-275 plants/m^2 and 45-405 plants/m^2, respectively). The most dominant weed *Echinochloa crus-galli* in rice and *Phalaris minor* in wheat did not develop any envisaged sign of herbicide resistance against continuous and rotational used herbicides in respective crops. Grain yields of rice under weed-free situations were better under GM (6.37-8.30 t/ha) than WGM (5.59-7.63 t/ha). Similarly, the grain yields of wheat were higher under GM (5.25-5.99 t/ha) than WGM (5.08-5.54 t/ha). Consequently, the overall system productivity was better under GM.

INTRODUCTION

Rice in India is grown over an area of about 43 mha with the total production of about 116 m tones, amounting to 41% of the total food grain in the country. Wheat is grown over an area of about 29 mha with total production of about 99 m tones, amounting to 35% of the total food grain production in the country. Rice and wheat crops contribute 76% of the total food grain production in India (Economic Survey 2018-19). It is the most important cropping system covering 10.5 mha area in India and supporting 600 million people. Due to continuous adoption of this monoculture, second generation problems such as declining factor productivity, stagnating crop productivity, declining soil organic matter, receding ground water table, diminishing farm profitability, and environment pollution have begun to appear (Hobbs and Gupta 2000, Sharma *et al.* 2003, Gupta and Sayre 2007, Chauhan *et al.* 2012). Enhanced use and/or abuse of agrochemicals to enhance agriculture production and to manage pests is resulting in reduced soil fertility and productivity and also negatively impacting human health. The use of green manuring is a positive preposition to limit the deleterious effects of agrochemicals.Besides improving the soil health and fertility, it also helps to manage the agricultural pests (Kumar *et al.* 2014). Green manuring has become a common environmentally important agricultural practice for soil quality restoration, maintaining soil organic matter, reclaiming degraded soils, and supplying the plant nutrients (Sinha *et al.* 2009, Kumar 2010). Increased fertilizer costs, pollution, and conservation of energy have further attracted the interest of researchers and low-input farmers in green manuring.Besides improving nutrient availability, green manure improves soil structure and drainage, and stimulates soil microbial growth and activity, with subsequent mineralization of plant nutrients (Eriksen 2005). The availability of N and P utilization is also enhanced due to green manuring.

One of the major benefits of green manuring is its ability to suppress weeds (Blackshaw *et al.* 2001). Green manures cover the ground extensively, which stop the weeds growing beneath them. Green manuring enriches the diversity of a rotation and reduces the opportunities of weeds to become adapted to a particular cropping pattern. *Phalaris minor* Retz. including herbicide resistant populations in wheat and *Echinochloa crus-galli* (L.) P. Beauv. in rice are the two dominant weeds associated with the rice-wheat cropping system (RWCS). In the present situation, intervention in the form of green manuring through *Sesbania aculeata* grown after wheat harvest may be instrumental in improving soil fertility, and avoiding or delaying the development of resistance in *P. minor* against commonly used herbicides (clodinafop, fenoxaprop, and sulfosulfuron). The use of green manures in-between successive crops helps maintain or increase organic matter in soil (Pung *et al.* 2004). *S. aculeata* upon its incorporation in the soil at the succulent stage adds 60-90 kg nitrogen per ha (Pandey *et al.* 2008) and helps to improve the physical and biochemical structure of the soil, prevents leaching losses of nutrients, enhances water holding capacity, prevents weed growth, reduces residual effect of chemicals, and helps in reducing the soil borne inoculum of phyto-pathogens (Kumar 2010). Keeping these points in view, present long-term study was initiated to monitor the long-term impacts of green manuring and continuous or rotational use of herbicides on weed infestation, and sustainability and productivity of the RWCS.

MATERIALS AND METHODS

A long-term field experiment was initiated at CCS Haryana Agricultural University, Regional Research Station, Karnal, Haryana, India during the 1999 rainy season to study the effect of green manuring and continuous or rotational use of herbicides on weed dynamics, sustainability, and productivity of rice and wheat and continued till 2015-16. The soil of the field was deficient in organic carbon (0.35%), sufficient in available phosphorus (12.0 kg P_2O_5/ha), and sufficient in potassium (205 kg/ha) at the beginning of this experiment.

The treatments included continuous (butachlor in rice and clodinafop in wheat) and rotational use of herbicides (pretilachlor, anilofos, and butachlor in rice; and isoproturon, fenoxaprop, pinoxaden, clodinafop, and sulfosulfuron in wheat) along with weedy and weed-free checks in both crops under green manuring (GM) and without green manuring (WGM) (**Table 1**). The treatments were arranged in a randomized complete block design with three replications with a plot size of 23.0 x 6.8 m and all the treatment plots were kept fixed over the years.

The results for this investigation for the years 1999 to 2008 have already been published earlier (Yadav *et al.* 2010a, b, c). Henceforth (from 2008 onwards), the details and results of the same long-term planned experiment have been presented. Due to a heavy buildup of broad-leaved weeds in the wheat crop, blanket sprays of metsulfuron 4 g/ha in winter 2008-09 and 2, 4-D 400 g/ha in winter 2009-10 was done in all plots after recording the weed data in wheat.

Across different years, *Sesbania* as the green manure crop was sown by broadcasting using a seed rate of 25 kg/ha in the month of May in fixed plots assigned to the green manuring treatments. *Sesbania* was incorporated into the soil when it was of knee-high height prior to transplanting of rice followed by ponding of water required for puddling. After puddling, rice was transplanted using 30-45 days old seedlings at a spacing of 20 x 15 cm in the month of July using the cultivar '*HKR-47*' (**Table 1**). Herbicides were applied at 3 days after transplanting (DAT) by broadcasting after mixing in 150 kg sand/ ha. In green manured plots, 25% less nitrogen was applied in rice as compared to non-green manured plots. Data on weed density were recorded at 60 DAT, and green yield at harvest. Harvesting of rice was done in the month of October.

After the harvest of rice, wheat was sown in the month of November during different years. Wheat cultivars '*DBW17*', '*DPW621-50*', '*WH711*', and '*HD2967*' were used for sowing in different years of experimentation (**Table 1**). The treatments included fixed herbicide (clodinafop 60 g/ha) and rotational herbicide (isoproturon, fenoxaprop, pinoxaden, clodinafop and sulfosulfuron). Sowing was done at a row spacing of 20 cm using 100-112.5 kg seeds/ha. Herbicides were applied at 35 days after sowing (DAS) using a knapsack sprayer fitted with a flat fan nozzle with a spray volume of 500 L/ha.

Data on weed density were recorded at 75 DAS, and green yield at harvest. Harvesting was done in the second fortnight of April. Both the crops (rice and wheat) were raised according to standard practices of the State Agricultural University.

Before statistical analysis, the data on density of weeds were subjected to square root transformation $(\sqrt{x+1})$ to improve the homogeneity of the variance. The year wise data were subjected to the analysis of variance (ANOVA), and the significant treatment effect was judged with the help of 'F' test at the 5% level of significance (Cochran and Cox 1957). The 'OPSTAT' software of CCS Haryana Agricultural University, Hisar, India, was used for statistical analysis (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

Effect on weeds in rice

Weed flora of the experimental field during different years in rice mainly included *Echinochloa crus-galli* (L.) P. Beauv. and *E. colona* (L.) Link.; among grasses, *Ammannia baccifera* L. and *Euphorbia microphyla* L. among broad-leaf weeds, and *Fimbristylis miliacea* (L.) Vahl, *Cyperus iria* L., *C. difformis* L., and *C. rotundus* L. among sedges with invariably minor variations over the seasons.

Green manuring resulted in reduced population of grasses, broad-leaf weeds (BLW), and sedges in rice during initial years up to 2008 (Yadav *et al*. 2010a). From 2009 onwards, grassy weeds in weedy check plots under GM (7-37 plants/m^2) remained lower or similar to WGM (6-37 plants/m^2) except in 2013 and 2014 (**Table 2**). Continuous use of butachlor (0-5 plants/m^2) and rotational use of herbicides (0-3 plants/m^2) over the years provided excellent and similar reductions in the population of grassy weeds and were as good as weed-free checks. All herbicidal treatments were superior to the weedy check in reducing grassy weed populations. Similarly, the density of BLW and sedges in weedy check plots was similar or lower under GM than WGM plots up to 2008 (Yadav *et al*. 2010a). Thereafter also the broad-leaf weeds and sedges in weedy check plots under GM (2-83 plants/m^2) remained lower or similar to WGM (23-106 plants/m^2) except in 2012 and 2014 (**Table 2**). No BLW and sedges were present in the field in 2011 and 2015. Herbicides used continuously (0-36 plants/m^2) or in rotation (0-46 plants/m^2) resulted in similar densities of BLW and sedges also. The efficacy of continuous or rotational herbicides at reducing populations of BLW and sedges was generally not influenced by green manuring; however, during 2002, 2008 (Yadav *et al*. 2010a), and 2009 (**Table 2**), efficacy of herbicides was slightly better under green manuring.

The efficiency of continuous or rotational herbicides against weeds was not much influenced by green manuring. There were no signs of development of resistance in weeds against the continuously used herbicide butachlor or rotationally used herbicides over the years since 1999. There were no signs of any adverse effect of continuous use of butachlor on the control of weeds including *Echinochloa crus-galli*, the most dominant weed. The rotational herbicides also performed very well for the control of *Echinochloa*, and were at par with butachlor (fixed herbicide). Similar results on long-term effects of

Table 1. Details of treatments during 2008-09 to 2015-16 in long-term experiment continued since 1999

Particulars	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
Rice								
Rotational herbicide	-	Pretilachlor	Anilofos	Butachlor	Pretilachlor	Anilofos	Butachlor	Pretilachlor
Variety	-	*HKR 47*	*HKR 47*	*HKR47*	*HKR47*	*HKR 47*	*HKR 47*	*HKR 47*
Date of transplanting	-	25.07.2009	07.07.2010	25.07.2011	15.07.2012	12.07.2013	17.07.2014	07.07.2015
Date of harvesting	-	25.10.2009	22.10.2010	31.10.2011	29.10.2012	25.10.2013	25.10.2014	27.10.2015
Age of seedling (days)		45	35	45	40	40	40	33
Wheat								
Rotational herbicide	Sulfosulfuron	Fenoxaprop	Clodinafop	Sulfosulfuron	Pinoxaden	Clodinafop	Sulfosulfuron	-
Variety	*DBW17*	*DBW17*	*DBW17*	*DPW621-50*	*DPW621-50*	*WH711*	*HD2967*	-
Date of sowing	30.11.2008	22.11.2009	19.11.2010	25.11.2011	20.11.2012	17.11.2013	05.11.2014	-
Date of harvesting	17.04.2009	20.04.2010	23.04.2011	23.04.2012	26.04.2013	24.04.2014	23.04.2015	-
Seed rate (kg/ha)	112.5	112.5	112.5	100	100	112.5	112.5	

Table 2. Long-term effect of continuous or rotational use of herbicides and green manuring on density of weeds in rice during 2009 to 2015 under rice-wheat system in plots maintained since 1999 (*Kharif* 2009 to 2015)

Treatment	Density of grassy weeds in rice (no./m^2)*							Density of broad-leaved weeds and sedges in rice (no./m^2)						
	2009	2010	2011	2012	2013	2014	2015	2009	2010	2011	2012	2013	2014	2015
Green manuring														
Fix herbicide	2.0(3)	1.0(0)	1.0(0)	2.0(3)	1.0(0)	1.0(0)	1.0(0)	3.4(11)	1.0(0)	1.0(0)	3.5(12)	3.6(13)	1.0(0)	1.0(0)
Rotational herbicide	2.2(5)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	4.1(18)	1.0(0)	1.0(0)	1.4(1)	4.3(18)	1.0(0)	1.0(0)
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	4.5(19)	4.6(21)	6.1(37)	4.6(21)	3.1(9)	6.0(35)	2.7(7)	9.2(83)	1.5(2)	1.0(0)	4.4(19)	3.5(12)	4.2(17)	1.0(0)
Without green manuring														
Fix herbicide	1.2(1)	1.0(0)	1.0(0)	1.2(1)	1.0(0)	1.0(0)	1.2(1)	5.8(36)	1.0(0)	1.0(0)	1.5(2)	1.0(0)	1.0(0)	1.0(0)
Rotational herbicide	1.0(0)	1.0(0)	1.0(0)	1.2(1)	1.0(0)	1.0(0)	1.0(0)	6.8(46)	1.0(0)	1.0(0)	2.4(6)	3.2(10)	1.0(0)	1.0(0)
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	4.3(19)	5.6(32)	5.7(32)	6.1(37)	2.6(6)	4.6(21)	2.6(6)	10.3(106)	4.3(23)	1.0(0)	2.6(6)	3.4(12)	3.3(10)	1.0(0)
LSD (p=0.05)	1.28	0.97	0.59	0.93	0.31	0.40	0.4	2.21	1.96	NS	1.55	1.38	0.62	NS

*Original values in parenthesis were subjected to square root transformation $(\sqrt{x+1})$ before analysis green manuring and continuous use of herbicides on weeds have been reported earlier as well (Yadav *et al.* 2010a, c). Lower weed density due to green manuring might be attributed firstly to emergence of weeds during *Sesbania* in the field, which were plowed down before transplanting of rice; and secondly to probability of some allellopathic effects of green manured crop. Reductions in weed infestations in rice due to *Sesbania* green cover crop have been reported by Yadav *et al.* (2011). However, increased weed infestation under green manuring during later years could be probably due to better growing conditions under green manuring both for crop and the weeds. Migliorini *et al.* (2008) did not find any significant effect of green manuring on weeds.

Effect on weeds in wheat

Weed flora of the experimental field mainly included *Phalaris minor* Retz. among grassy weeds, and *Lathyrus aphaca* L., *Coronopus didymus* L., *Vicia sativa* L., *Medicago denticulate* L., *Melilotus indica* L. and *Anagallis arvensis* L. among BLW with obviously some minor variations over the seasons.

The density of grassy weed *Phalaris minor* under weedy check plots was higher under GM at start of the experiment, but lower under GM up to 2005-06 and started increasing later on with similar populations in 2006-07 and higher population under GM in 2007-08 (Yadav *et al.* 2010a). From 2008-09 onwards, the density of *P. minor* in weedy check plots was invariably higher or similar under GM (55-229 plants/m^2) than WGM (45-177 plants/m^2) over the seasons (**Table 3**). Continuous use of clodinafop over the years provided excellent control of *P. minor* in terms of weed density and it was as good as the weed-free check in some seasons. Rotational use of herbicides also provided good control of *P. minor* in terms of weed density (0-50 plants/m^2)*;* however, it was similar or inferior to the continuously applied herbicide clodinafop (0-29 plants/m^2) over the years. All herbicidal treatments were superior to the weedy check in this respect. The efficacy of continuous or rotational herbicides in reducing the density of *P. minor* was generally not influenced by green manuring (1-50 plants/m^2 under GM and 0-41 plants/m^2 under WGM) (**Table 3**), with few exceptions (2001-02, 2003-04 and 2005-06) where weed density was lower under non-green manuring (Yadav *et al.* 2010a).

The population of BLW in weedy check plots under GM was lower than WGM during most of the seasons up to 2007-08 and there was very high buildup of *Lathyrus aphaca* population in non-green manured plots (Yadav *et al.* 2010a). From 2008-09 onwards, the density of BLW under weedy check plots in wheat was invariably lower under GM (19-275/m^2) than WGM (45-405/m^2) (**Table 3**). Similarly, under the fixed herbicidal treatment of clodinafop, which is a grass-killing herbicide, the density of BLW was at par or lower in GM (29-283 plants/m^2) than WGM plots (35-397 plants/m^2). The rotational use of herbicides improved control of BLW (29-189 plants/m^2) than the fixed herbicide (29-283 plants/m^2) treatment under green manuring. The rotational treatment of sulfosulfuron resulted in lowered infestations of BLW in this treatment. The differences between rotational and fix herbicide in respect of density of weeds were very much prominent. The efficacy of sulfosulfuron as rotational herbicides against BLW was invariably better under green manuring.

No signs of development of resistance in *P. minor* were observed against clodinafop used continuously over the years and even with the

Table 3. Long-term effect of continuous or rotational use of herbicides and green manuring on density of weeds in wheat during 2008-09 to 2014-15 under rice-wheat cropping system in plots maintained since 1999 (*Rabi* 2008-09 to 2014-15)

Treatment	Density of grassy weeds in wheat (no./m^2)*							Density of broad-leaved weeds in wheat (no./m^2)						
	08-09	09-10	10-11	11-12	12-13	13-14	14-15	08-09	09-10	10-11	11-12	12-13	13-14	14-15
Green manuring														
Fix herbicide	2.6(6)	2.4(6)	1.4(1)	1.2(1)	4.8(23)	3.0(10)	5.4(29)	10.3(105)	5.4(29)	5.5(29)	16.8(283)	14.1(198)	14.7(216)	15.3(233)
Rotational herbicide	4.8(23)	3.9(15)	2.1(4)	6.4(40)	5.1(25)	2.7(7)	7.1(50)	8.0(63)	6.3(39)	5.4(29)	7.7(59)	11.3(127)	13.8(189)	7.7(60)
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	9.4(88)	10.7(117)	7.5(55)	15.1(229)	14.3(205)	13.4(180)	14.6(213)	9.8(95)	4.4(19)	5.2(26)	16.6(275)	8.2(67)	8.8(78)	13.6(184)
Without green manuring														
Fix herbicide	2.8(9)	1.0(0)	2.9(9)	1.0(0)	3.2(10)	2.4(6)	5.4(29)	14.7(217)	6.0(35)	6.4(41)	19.9(397)	18.1(329)	19.6(385)	17.2(296)
Rotational herbicide	3.6(13)	1.0(0)	1.8(3)	4.8(23)	2.6(6)	2.2(5)	6.4(41)	14.3(205)	6.8(45)	6.8(45)	7.2(52)	14.8(219)	20.1(405)	8.3(70)
Weed free	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check	6.8(45)	7.4(55)	8.3(68)	13.3(177)	10.7(114)	10.1(102)	11.3(139)	14.3(205)	5.8(33)	6.8(46)	19.1(363)	10.8(118)	13.6(184)	15.6(243)
LSD (p=0.05)	1.20	1.81	1.56	1.38	1.80	1.87	1.36	1.66	1.02	0.86	2.38	1.85	1.37	1.87

*Original values in parentheses were subjected to square root transformation $(\sqrt{x+1})$ before analysis.Abbreviations: GM, with green manuring, WGM, without green manuring rotational herbicides. However, there was a slight reduction in the efficacy of the rotational herbicide sulfosulfuron during 2011-12, and 2014-15. Inclusion of pinoxaden as a rotational herbicide in place of fenoxaprop in 2012-13 proved better. The present long-term study indicated that *P. minor* initially decreased but increased with time due to green manuring, but BLW were reduced. BLW were found to increase under non-green manuring particularly in plots treated with fixed herbicides, as no broad-leaved herbicide was used over the years. Consequently, the infestation of BLW particularly *Lathyrus aphaca* under non-green manured plots became very serious in 2007-08, for which BLW herbicide was used across all the treatments to scale down its infestation. The higher density of *P. minor* under GM as compared to WGM could be due to improvement in soil conditions under GM with time, which proved favorable for *P. minor* as well, hence the weed started building up after some time. Long-term effects of green manuring in reduction of weed infestation initially in wheat and build up later on have been reported earlier as well (Yadav *et al.* 2010a, c). However, Migliorini *et al.* (2008) did not find any significant effect of green manuring on weeds.

Effect on rice crop productivity

Continuous or rotational use of herbicides provided statistically similar grain yield of rice (5.28-7.45 t/ha) which was better than weedy check plots (3.19-5.53 t/ha) both under GM and WGM (**Table 4**). The grain yield was highest under the weed free treatment (5.59-8.30 t/ha), which was similar or higher to the herbicidal treatments across different years. The grain yield under green manuring (3.66-8.30 t/ha) was higher than non-green manuring (3.19-7.63 t/ha) under different treatments over the years with few exceptions; however, the differences were not always significant. The grain yield of rice under weed free situations was better under GM (6.37-8.30 t/ha) than WGM (5.59-7.63 t/ha) over the years.

Effect on wheat crop productivity

The grain yield of wheat was higher under green manuring over the years; however, the differences were not significant with few exceptions (**Table 4**). The continuous or rotational use of herbicides provided statistically similar grain yield of wheat (4.52-5.80 t/ha), which was better than weedy check plots (1.65-3.86 t/ha) both under GM and WGM. The grain yield was highest under the weed free treatment (5.08-5.87 t/ha), which was similar or higher to the herbicidal treatments across different years. Grain yield of wheat in herbicide treated or weed free treatments under green manuring (4.75-5.99 t/ha) was higher than non-green manuring (4.52-5.58 t/ha) under different treatments over the years with few exceptions; however, the differences were not always significant.

The system productivity of the RWCS was higher under green manuring than non-green manuring. Increases in the yield of rice and measurable effects on the succeeding crop of wheat due to green manuring have been reported earlier also (Mann *et al.* 1994, Yadav *et al.* 2010a, b, c).

Green manuring reduced the population of grasses, BLW, and sedges in rice, however, with time weeds started building up in GM as well. In wheat, infestation of *Phalaris minor* was lower under green manuring initially, but increased with time and

Table 4. Long-term effect of continuous or rotational use of herbicides and green manuring on grain yield of rice (2009 to 2015) and wheat (2008-09 to 2014-15) under rice-wheat cropping system in plots maintained since 1999

Treatment	Grain yield of rice (t/ha)							Grain yield of wheat (t/ha)						
	2009	2010	2011	2012	2013	2014	2015	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15
With green manuring														
Fix herbicide	7.22	7.07	5.74	6.77	6.71	7.45	7.38	5.17	4.85	5.80	5.36	5.43	5.41	5.68
Rotational herbicide	6.94	6.85	5.61	6.66	6.65	7.41	7.47	5.09	4.75	5.60	5.31	5.44	5.17	5.69
Weed free	7.57	7.31	6.37	7.05	6.63	7.90	8.30	5.54	5.25	5.99	5.63	5.59	5.64	5.87
Weedy check	4.41	3.66	3.73	4.64	4.87	4.51	5.53	3.34	1.65	3.22	3.86	3.69	3.54	3.32
Without green manuring														
Fix herbicide	6.22	6.52	5.30	6.32	5.67	6.95	7.11	4.89	4.60	5.55	5.19	5.13	4.80	5.38
Rotational herbicide	5.97	6.35	5.28	6.23	5.65	7.14	7.14	4.71	4.52	5.47	5.14	5.14	5.18	5.40
Weed free	6.65	6.74	5.79	6.61	5.59	7.43	7.63	5.27	5.08	5.52	5.39	5.49	5.58	5.54
Weedy check	4.03	3.19	4.11	4.20	4.04	5.14	4.03	3.43	2.81	3.20	3.89	3.20	3.83	3.26
LSD (p=0.05)	0.69	0.46	0.66	0.42	0.45	0.25	0.20	0.33	0.38	0.31	0.27	0.32	0.41	0.29

became higher than non-green manuring. The BLW in wheat were invariably lower under GM. There were no signs of development of resistance in weeds including *Echinochloa crus-galli* against continuously (butachlor) or rotationally used herbicides (butachlor, pretilachlor, and anilofos) in rice, and *Phalaris minor* against continuously (clodinafop) or rotationally used herbicides (clodinafop, fenoxaprop, sulfosulfuron and pinoxaden) in wheat. Productivity of rice and wheat crops and RWCS as a whole were better under GM over the years. However, the impact on rice yield was more pronounced. This study established the importance of *Sesbania* green manuring in RWCS on long-term basis.

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Efficacy of herbicides against canary grass and wild oat in wheat and their residual effects on succeeding greengram in coastal Bengal

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ABSTRACT

A field trial was conducted at Regional Research Station (coastal saline zone), BCKV, Akshaynagar, Kakdwip, South 24 Parganas (WB) during winter seasons of 2016-17 and 2017-18 to study the bio-efficacy of pinoxaden against the canary grass (*Phalaris minor*) and wild oat (*Avena ludoviciana*) in wheat and its effects on succeeding greengram crop. Application of pinoxaden at 352.9 g/ha recorded significantly greater reduction of targeted weed populations; however, it was statistically at par with its two lower doses of 156.86 and 176.47 g/ha. The higher dose of pinoxaden had greater weed control efficiency (WCE). Pinoxaden at 352.94 g/ha resulted in significantly higher grain yield compared to other treatments. Lower doses of pinoxaden at 156.9 and 176.5 g/ha were at par with hand weeding for grain yield. Therefore, the application of pinoxaden 352.94 g/ha at 30 days after sowing (DAS) can be a good option for canary grass and wild oat management in wheat - greengram sequence in coastal Bengal.

INTRODUCTION

Rice production in coastal Bengal is not satisfactory mainly because of water crisis in winter season. Realizing rapid population growth, it is generally understood that rice alone could not meet the food requirements of this region. Wheat, preferably short duration cultivar, was therefore chosen as an alternative winter food crop. Furthermore, dietary preferences of local people are also changing and wheat is becoming a highly desirable food supplement to rice. However, weeds cause substantial losses in yield and quality of wheat crop in this part of the State. In wheat, weeds alone account for 10 to 80% yield losses depending upon weed species, severity and duration of weed infestation (Jat *et al.* 2003). *Phalaris minor* and *Avena ludoviciana* are major problematic grass weeds causing large scale reductions in wheat grain yield (Chhokar *et al.* 2012). To attain economic wheat yield, weeds must be removed during critical period of competition which falls in between 0 to 30 days of sowing (Saha *et al.* 2016). In other words, if the weeds are not controlled at the critical stages of crop growth, they may cause reduction in crop yield upto 66% (Kumar *et al.* 2011). For controlling weeds in wheat, farmers mostly rely on herbicides due to cost and time effectiveness.

Recently, many new molecules have been developed by different agro-chemicals industries. Pinoxaden, which belongs to phenyl-pyrazolin group has been introduced to tackle the problem of *P. minor* (Kaur *et al.* 2017). However, their efficacy needs to be tested. Every herbicide has an optimum dose, under a set of environments, for effective control of weeds. Under or over-dose of herbicide is not desirable as under-dose may be less effective and may facilitate development of resistance in weeds, while over-dose may result into phytotoxicity (Pawar *et al.* 2017). Taking due cognizance of above facts, a field experiment was conducted with the objectives to determine the effect of pinoxaden against *P. minor* (canary grass) and *A. ludoviciana* (wild oat) in wheat crop and to study the effect of pinoxaden on micro-flora of soil in cropped area besides determining the residual effect of herbicides if any on succeeding greengram crop.

MATERIALS AND METHODS

Field trial was set up at Regional Research Station (Coastal Saline Zone), Bidhan Chandra Krishi

Viswavidyalaya, Akshaynagar, Kakdwip, South 24 Parganas, West Bengal during winter season of 2016-17 and 2017-18. The farm is situated at 22°40´ N latitude, 88°18´ E longitude and 7 m above mean sea level. The land topography is referred as medium where the water stagnation never went beyond 30 cm. The soil was having clayey texture, pH of 7.31, organic carbon 0.64%, EC (1:2.5 :: soil:water) 1.79 dS/m, available N 156.0 kg/ha, available P 100.5 kg/ha and available K 321.3 kg/ha. The experimental plots were laid out in a randomized block design with seven treatments consisting of pinoxaden at 156.86 g/ha; pinoxaden at 176.47 g/ha; pinoxaden at 352.94 g/ha; fenoxaprop-p-ethyl at 12.90 g/ha; clodinafop propargyl at 26.67 g/ha; hand weeding at 15 and 30 DAS (days after sowing) and control or weedy plot with three replications. The individual plot size was 5 × 5 m. All the herbicides were applied at 30 DAS, when both the target weed species were at 3-4 leaf stage. The herbicides were sprayed with knapsack sprayer fitted with flat fan nozzle by dissolving in 300 liters water per hectare.

Before starting of present investigation, rice was continuously grown for the last five years during both rainy and winter seasons. Pre-sowing irrigation followed by ploughing with disc harrow, tiller and leveler was done for optimum seed germination. Before sowing, wheat seeds (cv. '*HD 2967*') were treated with tebuconazole at 1.0 g/kg of seed. In both years of experiment, seeds were sown on November 2 at 100 kg/ha at the distance of 20 × 5 cm in both the years of study. The recommended fertilizer dose of 60:80:40 kg N, P_2O_5 and K_2O/ha were applied. Full dose of P_2O_5 and K_2O plus 1/3rd N were applied as basal (at sowing time) and rest 1/3rd N at maximum tillering stage and 1/3rd at panicle initiation stage. Rouging of experimental plots is done to remove off-type and diseased plants. As per recommendation, rouging operation was done thrice at vegetative stage, 75% ear emergence and maturity stage. Apart from pre-sowing irrigation, five irrigations were given starting at 20 days after sowing (DAS) and thereafter, at 20 days interval. The test crop took 115 days for maturity and was harvested on February 24 in both the years of study. After harvesting of wheat, greengram (cv. '*Samrat*') was sown on March 1 and March 3 and harvested on April 30 and May 2 in 1st and 2nd years of study respectively. Standard agronomic management suitable for that region was provided to the succeeding crop.

An area of 0.25 m^2 was selected randomly at two spots by throwing a quadrate of 0.5 x 0.5 m, weed species were counted from that area and density was expressed in number per m^2. The collected weeds were first sun-dried and then kept in an electric oven at 70°C till the weight became constant and dry weight was expressed as g/m^2. The data on crop growth parameters and yield were also recorded both for wheat and succeeding greengram crops.

To assess the bio-efficacy of different herbicides on crops and weeds, weed control efficiency (WCE) was worked out using following equations respectively as suggested by Banerjee *et al.* (2018):

$$WCE = \frac{WDM_c - WDM_T}{WDM_C} \times 100$$

Where, WDM_C is the weed dry matter weight (g/m^2) in control plot; WDM_T is the weed dry matter weight (g/m^2) in treated plot.

The total monetary returns (gross return) of the economic produce obtain from wheat crop were calculated based on minimum support prices (` 15.25/kg) of Government of India for wheat. The gross return is expressed per hectare basis using following equation:

Gross return = Wheat yield ×minimum support prices

Net return per hectare basis was calculated by subtracting the total cost of cultivation from the gross returns. Benefit: cost ratio (B : C ratio) was calculated as follows:

$$\text{B: C ratio} = \frac{\text{Gross return}}{\text{Total cost of cultivation}}$$

As wide variation existed in data, number and dry weight of weeds were transformed through square-root ($\sqrt{x+0.5}$) method before analysis of variance. The germination parentage values for green gram were subjected to angular transformation ($\text{Sin}^{-1}\sqrt{x}$) before statistical analysis. All the collected data were analyzed statistically by the analysis of variance (ANOVA) technique using the STAR Software version 2.0.1 of International Rice Research Institute, Philippines, 2013. The differences between treatments means were tested on the significance level of $p \leq 0.05$.

RESULTS AND DISCUSSION

Effect on weed density, biomass and weed control efficiency

Weed flora in the experimental field was dominated by *P. minor* and *A. ludoviciana*, irrespective of the dates of observations, before as well as 15, 30 and 45 days after herbicide application.

The weedy plots were infested with the highest densities of above weed species at all dates of observations (**Table 1**). The densities of these two major weed species were significantly ($p \leq 0.05$) reduced by the applications of pinoxaden at all three doses (156.9, 176.5 and 352.9 g/ha), even with greater efficacy than other two popular tested herbicides like fenoxaprop-p-ethyl and clodinafop propargyl. The application of clodinafop propargyl was not effective against *P. minor* and *A. ludoviciana* populations. The herbicidal treatment with pinoxaden at 352.9 g/ha caused greater reduction of targeted weed populations; however, it was statistically at par with its two lower doses (156.9 and 176.5 g/ha). Other investigators also found effective control of *P. minor* and *A. ludoviciana* (Chhokar *et al.* 2007, Kaur *et al.* 2017) either with sole pinoxaden or pre-mixture of pinoxaden and clodinafop.

The biomass of these two weed species also differed significantly ($p \leq 0.05$) between herbicide treatments and followed a trend like that of weed density (**Table 2**). The herbicide pinoxaden, irrespective of the dose, was superior to other herbicide applications in reducing weed biomass. The highest dose of pinoxaden (352.9 g/ha) resulted in higher reductions in dry weight at 15, 30 and 45 days after herbicide applications. Applications of standard check fenoxaprop-p-ethyl and clodinafop propargyl exhibited considerably lower reduction in weed biomass and were statistically inferior to the pinoxaden.

Higher the dose of pinoxaden greater was the weed control efficiency (WCE). Hence, the greater WCE against both *P. minor* and *A. ludoviciana* was recorded with pinoxaden at 352.94 g/ha at all dates of observations, followed by its lower doses (156.9 and 176.5 g/ha) (**Table 3**).

Effect on yield components and yield of wheat

Yield components of wheat namely, number of effective tillers/m^2 and grains/ear were found to be the highest under two hand weeding done at 15 and 30 DAS in both the years of study, closely followed by the higher dose of pinoxaden (352.9 g/ha). For other components like ear length and test weight, the highest values were obtained with pinoxaden at 352.9 g/ha in both the years. All the measured yield components were recorded lowest under control (weedy) treatment during both the years (**Table 4**).

Different herbicidal treatments resulted in significant variations ($p \leq 0.05$) in grain yield of wheat (**Table 4**). Crop growth and grain yield were inversely related with weed interference. Hence, the wheat grain yield differences among different treatments were reflected in differential efficacy against *P. minor* and *A. ludoviciana*, and the treatments which gave better efficacy recorded the highest grain yield and vice-versa. Significantly highest grain yield was

Table 1. Population of targeted weeds (no./m^2) under different weed control treatments in wheat (mean data of 2 years)

Treatment	*Phalaris minor*				*Avena ludoviciana*			
	BHA	15 DHA	30 DHA	45 DHA	BHA	15 DHA	30 DHA	45 DHA
Pinoxaden at156.86 g/ha	3.12 (9.3)	1.44 (1.7)	2.38 (5.3)	2.66 (6.7)	2.97 (8.3)	1.46 (1.7)	2.48 (5.7)	2.80 (7.3)
Pinoxaden at 176.47 g/ha	3.03 (8.7)	1.05 (0.7)	1.34 (1.3)	2.02 (3.7)	3.02 (8.7)	0.88 (0.7)	1.46 (1.7)	1.86 (3.0)
Pinoxaden at 352.94 g/ha	3.07 (9.0)	0.88 (0.3)	1.05 (0.7)	1.56 (2.0)	2.94 (8.3)	1.05 (0.7)	1.05 (0.7)	1.34 (1.3)
Fenoxaprop-p-ethyl at 12.90 g/ha	2.97 (8.3)	1.46 (1.7)	2.74 (7.0)	3.23 (10.0)	2.97(8.3)	1.95 (3.3)	2.42 (5.3)	3.29 (10.3)
Clodinafop propargyl at 26.67 g/ha	2.97 (8.3)	1.56 (2.0)	2.96 (8.3)	3.36 (11.0)	2.97 (8.3)	1.77 (2.7)	2.79 (7.3)	3.43 (11.3)
Hand weeding at 15 and 30 DAS	0.71 (0)	0.71 (0)	0.88 (0.3)	1.34 (1.3)	0.71 (0)	0.71 (0)	0.88 (0.3)	1.05 (0.7)
Control (weedy)	3.18 (9.7)	3.53 (12.0)	4.17 (17.0)	4.67 (21.3)	2.96 (8.3)	3.34 (10.7)	4.17 (17.0)	4.77 (22.3)
LSD (p=0.05)	0.43	0.30	0.62	0.71	0.52	0.37	0.39	0.45

Original figures in parentheses were subjected to square-root transformation $\sqrt{x+0.5}$ before statistical analysis; DAS= Days after sowing; BHA= before herbicide application; DHA= Days after herbicide application

Table 2. Dry weight of targeted weeds (g/m^2) under different weed control treatments in wheat (mean data of 2 years)

Treatment	*Phalaris minor*				*Avena ludoviciana*			
	BHA	15 DHA	30 DHA	45 DHA	BHA	15 DHA	30 DHA	45 DHA
Pinoxaden at156.86 g/ha	11.7 (3.49)	3.8 (2.07)	6.4 (2.64)	9.3 (3.14)	12.8 (3.65)	3.5 (2.00)	7.8 (2.88)	12.3 (3.58)
Pinoxaden at 176.47 g/ha	12.2 (3.56)	1.5 (1.41)	3.5 (2.00)	7.9 (2.89)	15.0 (3.94)	1.7 (1.47)	5.1 (2.36)	9.5 (3.16)
Pinoxaden at 352.94 g/ha	11.9 (3.53)	1.0 (1.22)	2.3 (1.68)	6.1 (2.57)	13.4 (3.73)	2.4 (1.69)	2.0 (1.59)	6.3 (2.61)
Fenoxaprop-p-ethyl at 12.90 g/ha	12.8 (3.65)	3.9 (2.10)	8.2 (2.14)	12.8 (3.64)	11.5 (3.47)	4.9 (2.32)	9.2 (68.18)	13.7 (58.2)
Clodinafop propargyl at 26.67 g/ha	12.0 (3.53)	4.1 (2.14)	15.4 (3.99)	24.7 (5.02)	15.7 (4.03)	6.4 (2.63)	17.3 (4.22)	22.1 (4.75)
Hand weeding at 15 and 30 DAS	0 (0.71)	0 (0.71)	1.0 (1.22)	7.2 (2.77)	0 (0.71)	0 (0.71)	0.97 (1.21)	3.0 (1.87)
Control (weedy)	13.8 (3.78)	16.6 (4.14)	24.7 (5.02)	33.5 (5.83)	12.6 (3.62)	17.3 (4.22)	29.0 (5.43)	32.8 (5.77)
LSD (p=0.05)	3.50	1.52	5.24	5.68	2.57	2.86	6.17	3.76

Original figures in parentheses were subjected to square-root transformation $\sqrt{x+0.5}$ before statistical analysis. DAS= Days after sowing; BHA= Before herbicide application; DHA= Days after herbicide application

Table 3. Weed control efficiency (%) against targeted weeds as influenced by different weed control treatments (mean data of 2 years)

Treatment	*Phalaris minor*			*Avena ludoviciana*		
	15 DHA	30 DHA	45 DHA	15 DHA	30 DHA	45 DHA
Pinoxaden at156.86 g/ha	77.11	73.92	72.15	79.73	73.17	62.38
Pinoxaden at 176.47 g/ha	90.96	85.85	76.51	90.33	82.52	71.04
Pinoxaden at 352.94 g/ha	93.97	90.58	81.70	86.28	93.00	80.80
Fenoxaprop-p-ethyl at 12.90 g/ha	76.51	66.96	61.88	71.80	68.18	58.23
Clodinafop propargyl at 26.67 g/ha	75.30	37.73	26.27	62.77	40.45	32.62
Hand weeding at 15 and 30 DAS	100.00	95.96	78.60	100.00	96.66	90.85
Control (weedy)	-	-	-	-	-	-

DAS= Days after sowing, DHA= Days after herbicide application

Table 4. Yield of wheat as influenced by different weed control treatments

Treatment	No. of effective tillers/m^2			Ear length (cm)			No. of grain/ear			Test weight (g)			Grain yield (t/ha)		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Pinoxaden at156.86 g/ha	337.0	342.2	339.6	11.7	11.9	11.8	39.3	40.3	39.8	45.6	45.8	45.7	2.79	2.93	2.86
Pinoxaden at 176.47 g/ha	346.3	351.4	348.8	11.4	11.6	11.5	40.0	40.2	40.1	46.1	45.9	46.0	3.09	3.27	3.18
Pinoxaden at 352.94g/ha	351.7	359.8	355.4	12.5	12.8	12.6	42.0	42.5	42.2	47.1	46.9	47.0	3.18	3.29	3.24
Fenoxaprop-p-ethyl at 12.90 g/ha	318.7	328.0	323.4	11.3	11.6	11.4	37.7	39.3	38.5	46.0	46.6	46.3	2.75	2.84	2.80
Clodinafop propargyl at 26.67 g/ha	301.0	313.8	307.8	11.2	11.5	11.3	37.3	38.3	37.8	44.3	44.5	44.4	2.19	2.34	2.27
Hand weeding at 15 and 30 DAS	366.0	374.5	370.2	12.3	12.5	12.4	42.3	43.6	43.0	44.1	44.5	44.3	3.36	3.48	3.42
Control (weedy)	237.0	246.3	241.7	10.0	10.2	10.1	37.0	38.9	38.0	42.4	42.8	42.6	1.70	1.79	1.75
LSD (p=0.05)	13.81	19.70	11.04	1.1	0.9	0.6	4.6	3.9	2.7	1.8	2.7	1.5	1.09	1.21	1.16

DAS= Days after sowing

Table 5. Economics of wheat cultivation as influenced by different weed control treatments

Treatment	Gross return (x10^3 `/ha/year)		Net return (x10^3`/ha/year)		B:C ratio	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Pinoxaden at156.86 g/ha	42.55	44.68	12.48	14.61	1.42	1.49
Pinoxaden at 176.47 g/ha	47.12	49.87	17.00	19.74	1.56	1.66
Pinoxaden at 352.94g/ha	48.49	50.17	18.14	19.82	1.60	1.65
Fenoxaprop-p-ethyl at 12.90 g/ha	41.94	43.31	11.46	12.83	1.38	1.42
Clodinafop propargyl at 26.67 g/ha	33.40	35.68	2.81	5.09	1.09	1.17
Hand weeding at 15 and 30 DAS	51.24	53.07	16.67	18.50	1.48	1.54
Control (weedy)	25.92	27.30	-3.33	-1.95	0.89	0.93

recorded with hand weeding (HW) treatment while weedy check plots recorded lowest grain yield of wheat on both the years. Among the herbicidal treatments, the pinoxaden at 352.9 g/ha resulted in significantly higher grain yield as compared to weedy and other herbicide treatments followed by pinoxaden at 156.9 and 176.5 g/ha being statistically at par with the yield obtained with HW treatment. Application of pinoxaden (352.9 g/ha) controlled weeds better for 45 days or more and helped wheat plants to grow in less weedy situations. In lesser weed environments, improved resource-use due to herbicide treatments might have led to a significant yield advantage, increased uptake of nutrients and might have provided better rooting and ground cover as well as higher water-use efficiency (Banerjee *et al.* 2018). Also, the weed management treatments might have significantly reduced the uptake of nutrients by weeds, which concurrently provided better environment for crop growth characteristics and yield attributes (Kien *et al.* 2016). Pawar *et al.* (2017) also obtained the higher grain yield of wheat with pinoxaden due to lower weed density and weed biomass, which might have caused less weed competition with wheat and resulted in the production of higher yield attributes and grain yield.

Economics of wheat cultivation

In terms of monetary returns, all the weed control treatments were superior over control (weedy) treatment during both the years (**Table 5**). The highest net return and B:C ratio were fetched by pinoxaden at 352.9 g/ha, closely followed by its lower dose (176.5 g/ha). Weedy plots resulted in lowest monetary returns in both the years due to poor crop yield realized at this growing situation.

Phytotoxicity of herbicides on wheat

The wheat plants were critically examined for phytotoxic symptoms at 1, 3, 5, 7 and 10 days after

Table 6. Soil micro-flora (cfu × 10^6/g of soil) at 0-15 cm depth (mean data of 2 years)

Treatment	Before spray at 30 DAS			After spray at 60 DAS		
	Bacteria	Fungi	Actinomycetes	Bacteria	Fungi	Actinomycetes
Pinoxaden at156.86 g/ha	75.88	23.97	20.63	77.20	24.23	23.00
Pinoxaden at 176.47 g/ha	78.19	27.02	21.26	78.42	27.86	22.73
Pinoxaden at 352.94 g/ha	88.74	31.68	22.96	88.81	33.09	22.03
Fenoxaprop-p-ethyl at 12.90 g/ha	75.68	23.77	19.68	71.10	25.50	19.09
Clodinafop propargyl at 26.67 g/ha	65.81	22.38	18.27	68.11	24.40	19.81
Hand weeding at 15 and 30 DAS	67.01	21.66	20.81	67.27	22.34	21.40
Control (weedy)	74.77	24.37	23.31	77.76	25.51	25.00
LSD (p=0.05)	9.17	2.93	NS	7.15	2.98	NS

DAS= Days after sowing; NS= Non-significant

Table 7. Effect of different herbicide treatments on growth and yield of greengram

Treatment	Germination (%)			Plant height (cm)			Grain yield (kg/ha)		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Pinoxaden at156.86 g/ha	77.1 (95.0)	85.3 (99.0)	81.8 (97.0)	57.3	60.6	59.0	780.0	975.3	788.3
Pinoxaden at 176.47 g/ha	80.7 (97.0)	86.7 (99.0)	82.0 (98.0)	60.2	62.3	61.3	858.3	832.3	845.0
Pinoxaden at 352.94 g/ha	82.3 (97.3)	87.3 (99.3)	85.7 (98.3)	62.9	64.5	63.7	888.7	873.3	881.3
Fenoxaprop-p-ethyl at 12.90 g/ha	82.8 (97.7)	83.9 (98.3)	83.4 (98.0)	52.9	53.9	53.4	688.3	702.7	696.3
Clodinafop propargyl at 26.67 g/ha	83.0 (97.7)	83.0 (97.7)	83.0 (97.7)	56.9	52.5	54.7	731.7	708.3	720.0
Hand weeding at 15 and 30 DAS	82.3 (97.3)	87.3 (99.3)	85.7 (98.3)	64.3	62.4	63.4	919.0	901.3	910.3
Control (weedy)	76.6 (94.7)	74.5 (92.7)	75.5 (93.7)	52.3	49.4	50.9	619.0	592.7	606.0
LSD (p=0.05)	NS	NS	NS	6.9	5.6	6.1	74.0	53.6	24.1

Original figures in parentheses were subjected to angular transformation ($\text{Sin}^{-1}\ \sqrt{x}$) before statistical analysis; DAS= Days after sowing; NS= Non-significant

herbicide application. The level of phytotoxicity was estimated by visual assessment based on Phytotoxicity Rating Scale (PRS) 0 to 10, where 0 = No crop injury while 10 = Heavy injury or complete destruction of test crop. No phytotoxicity was found like epinasty, hyponasty, necrosis, vein clearing, wilting and leaf injury on tip/surface in the plants treated with pinoxaden at 156.9, 176.5 and 352.9 g/ha in wheat, which indicated safety of this herbicide. No phytotoxicity on wheat crop treated either with sole pinoxaden or pre-mixture of pinoxaden and clodinafop was also observed by Kaur *et al.* (2017) and Sasode *et al.* (2017).

Effect on soil micro-flora

Herbicide treatments did not cause significant inhibition in soil fungal populations (**Table 6**). The herbicides were applied at 30 DAS, and observations were recorded at 60 DAS. By that time, herbicides might have undergone degradation by micro-organisms, and their effects got mitigated (Banerjee *et al.* 2018). The pinoxaden at 352.9 g/ha resulted in significantly ($p \leq 0.05$) greater fungal populations (bacteria and fungi) compared to other treatments, except the pinoxaden at 176.5 g/ha. The actinomycetal populations were similar between weedy and all tested herbicides.

Effect on growth and yield of succeeding greengram crop

The data on germination of the succeeding greengram crop (cv. Samrat) was recorded at 15 DAS in both the years, and it did not show any significant variation amongst the different herbicidal treatments applied in the previous wheat crop. The plant height of greengram varied significantly ($p \leq 0.05$) among the treatments, and it was higher with pinoxaden at 352.9 g/ha; being statistically at par with the height obtained with HW treatment (**Table 7**). The application of tested herbicides at different doses in the previous wheat crop did not leave any phytotoxic effect on the succeeding crop greengram.

Herbicidal treatments applied in wheat resulted in significant improvements ($p \leq 0.05$) in seed yield of succeeding crop greengram in both the years of study (**Table 7**). The treatments which gave best efficacy in wheat field also resulted the highest seed yield of greengram. The maximum seed yield was recorded with hand weeding treatment. Amongst the herbicidal treatments, application of pinoxaden at 352.9 g/ha resulted in significantly higher seed yield of greengram compared to weedy situation and other herbicide treatments in both the years. Probably, due to longer persistence in soil (half-life 23.7 days), the pinoxaden was found to have some residual effects on weeds in the succeeding greengram crop. In contrary, severe weed interference could result in much lower seed yield in unweeded plots, emphasizing the need for weed control either in preceding wheat crop or succeeding greengram crop.

The present investigation conclusively inferred that all the three doses of pinoxaden applied at 30 DAS were more effective against *P. minor* and *A. ludoviciana* than other tested herbicides. But the highest dose of pinoxaden (352.9 g/ha) brought about the maximum weed suppression, leading to highest yield of wheat and succeeding greengram crop. This offered slight residual weed control in succeeding greengram crop. The herbicide pinoxaden was found to be non-phytotoxic to wheat plant. It did not leave any phytotoxicity to the succeeding crop greengram as well. Therefore, the application of pinoxaden at 352.9 g/ha at 30 DAS may be recommended for better weed management in wheat followed by greengram in coastal Bengal.

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Metsulfuron-methyl residues in soil and wheat under North-Western mid-hill conditions of Himalaya

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ABSTRACT

A field experiment was laid out in a randomized block design consisting of metsulfuron-methyl (a herbicide) treatments at 2, 4, 8 g/ha along with control during two consecutive years to study metsulfuron-methyl degradation in soil and terminal residues in wheat straw and grain. Soil samples were collected at 0 (4 hr), 1, 3, 7, 10, 15, 30, 45, 60, 75 and 90 days after herbicide application for degradation studies. Wheat straw and grain were collected at the time of harvest for terminal residues study. The herbicide residues were quantified using high performance liquid chromatography (HPLC) equipped with UV-Vis detector using C-18 column. The degradation data generated in the present investigation during both the years indicated that higher dose of metsulfuron methyl *i.e.* 8 g/ha persisted in soil upto 45 days after herbicide application. The degradation was rapid and more than 90% of applied metsulfuron-methyl in soil dissipated within 15 days of application. The logarithmic plots of herbicide concentration at different doses versus time fitted first order kinetics decay curves during both years. At the time of harvest, the metsulfuron-methyl residues were non-detectable level in wheat straw and grain. Thus, the use of metsulfuron-methyl in wheat could be considered safe.

INTRODUCTION

In India, wheat is the second major food crop next to rice in terms of its production and consumption. This crop is heavily infested with weeds and on an average reduced grain yield by 66% (Kumar *et al*. 2011). Nowadays, herbicides are commonly used in Indian agriculture so as to reduce yield loss and maintain the quality of crop produce. Sulfonylureas, a family of broad action spectrum herbicide is widely used in many parts of the world to control weeds (Zanardini *et al*. 2002). Among the sulfonylureaa, metsulfuron-methyl (Methyl-2-(4-methoxy-6-methyl-1,3,5-triazin-2-yl carbamoyl sulfamoyl) benzoate) is used to control broad-leaf weeds in various plantation crops including the wheat due to its selective herbicidal activity (Singh and Singh 2002). It is biologically active at low application rates (2-100 g/ha). It acts as an inhibitor of acetolactate synthase (ALS), which retards the cell division in shoots and roots of the plant. ALS is the first enzyme involved in the biosynthesis of the branched chain amino acids valine, leucine and isoleucine in both plants and micro-organisms. Metsulfuron-methyl is rapidly taken up by the plants through roots and foliage, which alters the plant metabolism.

Metsulfuron-methyl is weak acid with pKa from 3 to 5 and in soils exists mainly in the ionized (anionic) form, repelled by negative charge of soil surfaces and exhibit low sorption to soils (Joshi *et al*. 1985). Metsulfuron-methyl is degraded both by chemical hydrolysis and soil micro-organisms. Herbicide-soil interaction depends on the chemical structure of the herbicide and the properties of soil. The degradation of herbicide is affected by several soil and environmental factors like pH, temperature, organic matter, soil moisture, microbial activity etc. The degradation rates of sulfonylureas are negatively correlated with soil pH. The chemical will degrade faster under acidic conditions, and in soils with higher moisture content at higher temperature. The chemical has higher mobility potential in alkaline soils than in acidic soils, as it is more soluble under alkaline conditions.

However, frequent use of metsulfuron-methyl herbicide to control the weeds in wheat field result in low efficacy and may lead to long term adverse effects in environment. It has been found that the extremely low levels of metsulfuron-methyl residues are phytotoxically sensitive to many crops in crop-rotation system (Li *et al*. 2005). Studies have also revealed that metsulfuron-methyl residues contaminate surface and ground water due to leaching and transport of herbicides and have unintended side effects on non-target organisms (Perkova and Donkova 2003). Metsulfuron-methyl herbicide possesses high solubility in water which indicates its high potential for movement in soil. These toxic effects of herbicides in environment at certain level of doses can be controlled by implementing good agriculture practices. Thus, it is important to understand the environmental fate of metsulfuron-methyl in soil and determine impact of its residues. Taking these concerns into account, the study was conducted to determine the degradation behaviour of metsulfuron-methyl at different doses in soil, wheat straw and grain.

MATERIALS AND METHODS

Field experimentation

A field experiment consisting metsulfuron-methyl treatments at 2,4,8 g/ha, along with control (water alone) was conducted at the Research Farm of Department of Agronomy, CSKHPKV, Palampur, India in a randomized block design with five replications during two years of study. Plots of 4.1 x 2.0 m were prepared and sown with wheat variety '*HPW155*' in 22.5 cm row spacing for each treatment. During both the years, metsulfuron-methyl as Supergrip (WP) containing 20% active ingredient was sprayed in the plots.

Reagents and chemicals

All solvents used in study were of analytical grade and purchased from Merck India Pvt. Ltd. Metsulfuron-methyl and its three major metabolites *i.e.* Methyl-2-sulfonyl amino benzoate (compound II), Saccharin (compound III) and 2-amino-6-methoxy-4-methyl triazine (compound IV) were procured from Sigma Aldrich, India.

Sample collection

The soil samples were drawn randomly from 0-15 cm depth using a tube auger from 6-7 spots in each of treated and untreated plots. Soil samples were collected at 0 (2 h), 1, 3, 5, 7, 10, 15, 30, 45, 60, 75, 90 days after herbicide application and at harvest (180 days). These soil cores were mixed together, air dried, powdered and passed through a 2mm sieve to achieve uniform mixing. Soil samples were sealed in polythene bags and stored in desiccator and analysed for metsulfuron-methyl residues. Wheat straw and grain samples were collected at the maturity of crop for terminal residual analysis.

Preparation of standards

Metsulfuron-methyl (10 mg) was dissolved in HPLC grade methanol in 10 mL volumetric flask to prepare stock solution of 1000 µg/mL (1000 ppm). From this stock solution, a working solution of 100 µg/mL (100 ppm) was prepared using methanol. The analytical standards were prepared in the range of 2, 1, 0.5, 0.1, 0.05 and 0.01 ppm in methanol by serial dilution technique. 20 µL volume of each solution was injected into HPLC for analysis. Calibration curve was prepared by plotting concentration vs average peak area. Solutions of compounds II, III, IV were also prepared and calibrated in similar way.

Sample processing and extraction for herbicide residue analysis

Extraction and clean-up for residue analysis was carried out in soil, wheat straw and grain as described by Sondhia (2008) with slight modification. Representative soil samples were taken in 250 mL flask and extracted by shaking for 1 hr. on a horizontal shaker with 50 mL of 80% methanol (in deionized water) containing 0.5% glacial acetic acid. The contents were filtered through Buchner funnel. The soil was subjected to the same extraction step for one more time. The combined filtrate was then concentrated and residues were dissolved in 5 mL of methanol for HPLC analysis. However, clean up step was not required in case of soil substrate.

Powdered samples of wheat grains and straw were dissolved in 80 mL of methanol and deionized water (80:20) containing 0.5 per cent glacial acetic acid. The contents were shaken on a horizontal shaker for 1 hr. and were filtered through Whatman filter paper no. 1 using activated charcoal. This step was repeated twice. The collected filtrate was partitioned with 50 mL of dichloromethane thrice. Dichloromethane layer was collected and solvent was concentrated to approximately 3 ml on a rotary vacuum evaporator. For clean-up, a mixture of florisil (2 g) and activated charcoal (0.5 g) was packed in the glass column (2 cm id 30 cm long) sandwiched by anhydrous sodium sulphate (4 g) on both the sides. After pre-washing of column with methanol the concentrated extract was added at the top and eluted with methanol. Eluents was collected and solvent was concentrated on a rotary vacuum evaporator to dryness and dissolved in 5 mL methanol for HPLC analysis. To ascertain the extraction efficiency of metsulfuron-methyl, recovery experiments were carried out in soil, wheat straw and wheat grain fortified with 0.25, 0.50 and 1.0 µg/g of metsulfuron-methyl.

Instrumentation

Shimadzu HPLC equipped with UV detector and Lichrosphere column C-18 (25 cm × 4.6 mm, 5 µm) column was used for the quantification of residues of metsulfuron-methyl. Detection was done at 230 nm wavelength using methanol:water (70:30) containing 1% glacial acidic acid as a mobile phase with flow rate at 1 ml/min. Injection volume was 20 µl. Retention time for metsulfuron-methyl was found to be 4.3 minute.

RESULTS AND DISCUSSION

Validation of HPLC method for metsulfuron-methyl analysis

HPLC is the most widely used analytical technique for micro level analysis. This technique offers the analysis with speed, accuracy, reproducibility and sensitivity and has been found to be useful in the quantitative determinations. Retention value of metsulfuron-methyl was found to be 4.3 minutes. The calibration curve was linear over the concentration ranged from 0.01 to 2 µg/mL with a regression equation of y=224055x+5015 and regression coefficient r^2=0.99. This method has been adopted to analyze the herbicide residues. Metsulfuron-methyl recoveries in soil were 86.0, 83.0 and 84.2% for fortification at the level of 0.25, 0.50 and 1 µg/g respectively. From spiked samples of wheat straw and wheat grain, the per cent recoveries of metsulfuron-methyl were 81.6, 83.5 and 80.0; and 80.6, 79.0 and 78.0 at the level of 0.25, 0.50 and 1 µg/g, respectively (**Table 1**). The above per cent recoveries are well within acceptable limits and are in direct conformity with findings of other workers (Sondhia 2008, Sanyal *et al.* 2006).

Residues of metsulfuron-methyl under field conditions

Terminal residues of metsulfuron-methyl in wheat straw and grain were determined by estimating metsulfuron-methyl concentration at the maturity of the crop. It was found that residues of metsulfuron-methyl were below detectable level (≤ 0.02 µg/g) in both straw and grain samples at harvest. The above findings are in conformity with results of Sondhia (2008), Paul *et al.* (2009).

Table 1. Per cent recoveries of metsulfuron-methyl from different matrices fortified with known amount of herbicide

Herbicide	Amount added µg/g	*Average amount recovered µg/g	Average recovery (%)
Soil	0.25	0.215± 0.005	86.0
	0.50	0.410±0.014	83.0
	1.00	0.841±0.018	84.2
Wheat straw	0.25	0.204±0.012	81.6
	0.50	0.418±0.011	83.5
	1.00	0.800±0.006	80.0
Wheat grain	0.25	0.202±0.014	80.6
	0.50	0.395±0.017	79.0
	1.00	0.780±0.019	78.0

*Values are mean of five determinations with standard deviation (±)

The data on degradation and per cent dissipation of metsulfuron-methyl in soil for two *Rabi* seasons at different doses have been presented in **Table 2**. Initial residues (0 day) of metsulfuron-methyl in soil immediately after application of metsulfuron-methyl applied at 2, 4 and 8 g/ha during first and second year of experiment were 0.112 and 0.119 µg/g, 0.218 and 0.230 µg/g and 0.402 and 0.448 µg/g, respectively. After 1 day of herbicide application, residues reached to 0.083 and 0.087 ug/g, 0.170 and 0.183 µg/g, and 0.323 and 0.341 µg/g, respectively at 2, 4 and 8 g/ha during first and second year. Approximately 40.2 and 41.1% at 2 g/ha, 33.5 and 34.8% at 4 g/ha, and 36.8 and 34.8 % at 8 g/ha of metsulfuron-methyl remained in soil on 5 days after herbicide application during both the years of study. The data on per cent dissipation of metsulfuron-methyl revealed that approximately 90% applied metsulfuron-methyl dissipated within 15 days of herbicide application at all the three levels of metsulfuron-methyl. During first year of study, on 30 days after herbicide application, the metsulfuron-methyl concentration was found to be 0.001 µg/g when applied at 2 g/ha. Whereas, it was below detectable levels during second year indicated that applied metsulfuron-methyl has dissipated completely. At 45 days after herbicide application, per cent dissipation in first year and second year for metsulfuron 8 g/ha were 99.3% and 99.6% indicating that only less than 1 per cent of applied metsulfuron-methyl was left in the soil during both the years.

The residues of metsulfuron-methyl exhibited a declining pattern as a function of time. It could be seen from the data that the rate of dissipation was very rapid during initial 10 days and thereafter becomes slow. The residues were decreased gradually with passage of time and below detectable level on 60 days after herbicide application during both years of experiment. Almost similar observations have been reported by Sanyal *et al.* (2006). It is quite likely that faster dissipation of metsulfuron-methyl in soil may be due to chemical and microbial dissipation mechanism. In acidic soils (pH less than 7) initial step in the degradation of parent herbicide is chemical hydrolysis however, further degradation of parent compound and its metabolites to CO_2 requires microbial activity. The chemical hydrolysis of metsulfuron-methyl in soil involved cleavage of sulfonylurea bridge, O-demethylation as well as third mechanism, triazine ring opening (Sarmah and Sabadie 2002). Microbial breakdown depends upon the type of microorganisms present in the soil that resulted into rapid disappearance of herbicide. The demethylation of triazine ring and

Table 2. Residues of metsulfuron-methyl and per cent dissipation in soil (0-15 cm) treated at different doses

Days after herbicide application	Residues (µg/g) At dose 2 g/ha		At dose 4 g/ha		At dose 8 g/ha	
	First year	Second year	First year	Second year	First year	Second year
0	0.112 ± 0.017(0.0)	0.119 ± 0.021(0.0)	0.218 ± 0.018(0.0)	0.230 ± 0.023(0.0)	0.402 ± 0.026(0.0)	0.448 ± 0.019(0.0)
1	0.083 ± 0.006(25.9)	0.087 ± 0.013(26.9)	0.170 ± 0.015(22.0)	0.183 ± 0.018(20.4)	0.323 ± 0.023(19.7)	0.341 ± 0.015(23.9)
3	0.062 ± 0.008(44.6)	0.065 ± 0.006(45.4)	0.123 ± 0.016(43.6)	0.160 ± 0.011(30.4)	0.234 ± 0.017(41.8)	0.250 ± 0.011(44.2)
5	0.045 ± 0.010(59.8)	0.049 ± 0.009(58.8)	0.073 ± 0.006(66.5)	0.080 ± 0.009(65.2)	0.148 ± 0.008(63.2)	0.156 ± 0.009(65.2)
7	0.032 ± 0.011(71.4)	0.034 ± 0.008(71.4)	0.054 ± 0.003(75.2)	0.059 ± 0.010(74.3)	0.099 ± 0.005(75.4)	0.115 ± 0.005(74.3)
10	0.014 ± 0.002(87.5)	0.019 ± 0.004(84.0)	0.047 ± 0.004(78.4)	0.048 ± 0.007(79.1)	0.087 ± 0.007(78.4)	0.093 ± 0.006(79.2)
15	0.006 ± 0.005(94.6)	0.007 ± 0.002(94.1)	0.019 ± 0.007(93.3)	0.024 ± 0.006(89.9)	0.027 ± 0.004(91.3)	0.045 ± 0.002(89.6)
30	0.001 ± 0.002(99.1)	BDL	0.003 ± 0.002(98.6)	0.004 ± 0.005(98.3)	0.008 ± 0.010(98.0)	0.009 ± 0.003(97.9)
45	BDL	BDL	0.001 ± 0.002(99.5)	BDL	0.003 ± 0.002(99.3)	0.002 ± 0.004(99.6)

BDL = Below detection limit, Conc. of Metsulfuron-methyl residues at 60, 75, 90 days post herbicide application was BDL.Values in parentheses indicates percent dissipation of metsulfuron-methyl at different doses

cleavage of the sulfonilureic bridge are the two different pathways identified for metsulfuron-methyl degradation by microbial activity (Zanardini *et al.* 2002). In the soil, increase in microbial activity is directly proportional to the decrease in concentration of herbicide in soil, thus increasing rate of dissipation (Morrica *et al.* 2001).

Another important contributing factor in present study for faster degradation of metsulfuron-methyl in soil might be acidic nature (pH 5.2) of experiment field. Bayer *et al.* (1988) reported that adsorption of sulfonylureas decreases on increase in soil pH due to increase amount of anionic species. Similar results of faster degradation of metsulfuron-methyl under acidic conditions and in soils with higher moisture content at higher temperature has been reported by Smith (1986). The logarithmic plots of herbicides residues versus time for first and second year of study have been presented in **Figure 1**. The plots indicated that the dissipation of metsulfuron-methyl at all levels of application, *viz.* 2, 4, 8g/ha fitted first order kinetics decay curve during both years.The half-life values were 3.54, 4.93, 6.40 days during first year of metsulfuron-methyl treatment at 2, 4, 8 g/ha respectively. Half-life values were 3.76, 5.19, 5.90 days during second year at 2, 4, 8 g/ha of metsulfuron-methyl respectively.

During second year of study (*Rabi* 2014-15), a HPLC method was developed for simultaneous identification of metsulfuron-methyl (I) and its three major metabolites *i.e.* Methyl-2-sulfonyl amino benzoate (II), 2-amino-6-methoxy-4-methyl triazine (III) and saccharin (IV). The retention values for metsulfuron-methyl and its three major metabolites *i.e.* Methyl-2-sulfonyl amino benzoate, 2-amino-6-methoxy-4-methyl triazine and saccharin were found to be 4.17 min, 3.19 min, 2.68 min and 3.75 min respectively as shown in **Figure 2**.

Wheat field soil samples of metsulfuron-methyl applied at recommended dose *i.e.* metsulfuron-methyl 4 g/ha were analysed at 15 days intervals for the identification of degradation products. HPLC analysis of field samples indicated the presence of metsulfuron-methyl in soil samples collected at zero and 15 days after herbicide application. At zero day, there were no traces of metabolites. However, at 15 days after herbicide application, metabolites *i.e.* 2-amino-6-methoxy-4-methyl triazine and methyl-2-sulfonyl amino benzoate were identified indicative of formation of these metabolites. At 30 days after herbicide application, metabolites 2-amino-6-methoxy-4-methyl triazine and methyl-2-sulfonyl amino benzoate were found along with third metabolite saccharin. However, there was no trace of

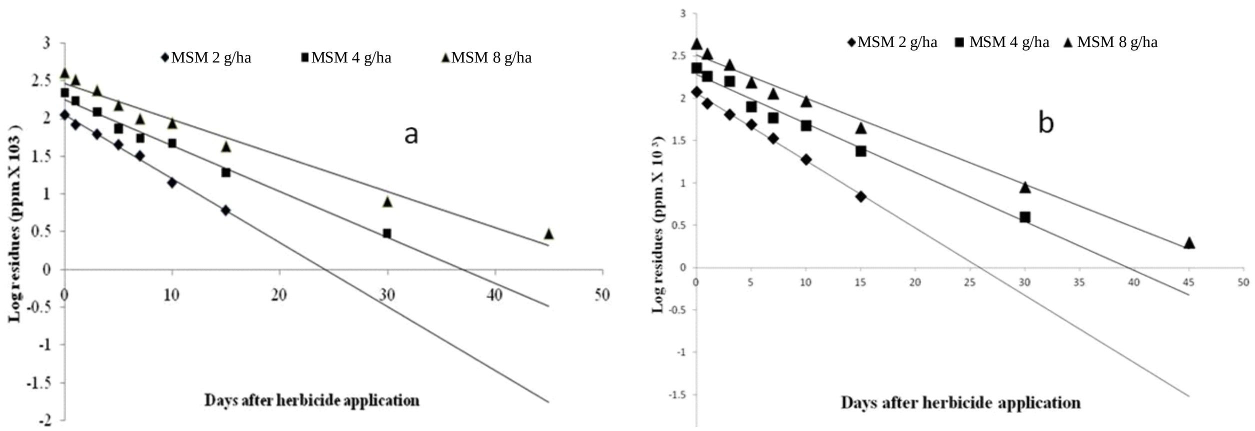

Figure 1. First order degradation behaviour of metsulfuron-methyl at 2, 4, 8 g/ha in soil a) First year, b) Second year

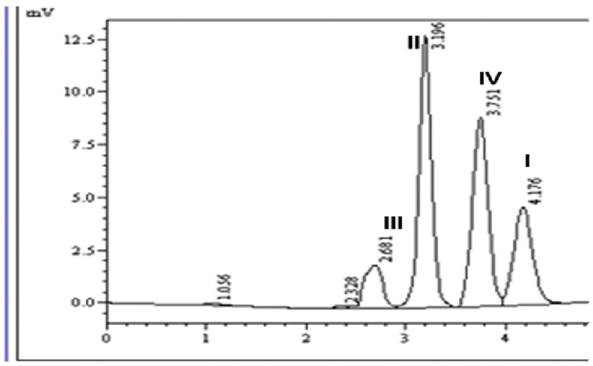

Figure 2. Chromatogram showing retention value of metsulfuron-methyl alongwith three major metabolites

parent compound metsulfuron-methyl on 30 days after herbicide application. Neither parent compound metsulfuron-methyl nor its metabolites *i.e.* 2-amino-6-methoxy-4-methyl triazine; methyl-2-sulfonyl amino benzoate and saccharin could be identified in soil samples collected at 45 days after metsulfuron-methyl 4 g/ha application. These results clearly indicated that at recommended dose of metsulfuron-methyl, residues persisted only upto 30 days and do not leave any residues in soil.

In the present study, the experimental field is acidic in nature (pH 5.2) therefore both the processes (chemical hydrolysis and microbial) occurs simultaneously for degradation of parent compound. Parent compound (metsulfuron-methyl) undergo chemical hydrolysis in initial step and do not require presence of microorganisms for the formation of three major products *i.e.*2-amino-6-methoxy-4-methyl triazine, methyl-2-sulfonyl amino benzoate and saccharin that includes breakdown of sulfonylurea bridge, O-demethylation of methoxy triazine and triazine ring opening. The further degradation of saccharin to CO_2 carried out in the presence of viable microorganisms (Anderson and Dulka 1985).

An almost similar result was obtained by Paul *et al.* (2008). In their study, they reported presence of metsulfuron-methyl in 0 and 7 day samples under field conditions. Initiation of two metabolities *i.e.* 2-amino-6-methoxy-4-methyl triazine, methyl-2-sulfonyl amino benzoate was found on 15th day. These two metabolites were found in major quantity on 20th day along with third metabolite saccharin. However, parent herbicide completely disappeared from soil surface on 20th day of herbicide application. They reported that formation of these compounds were mainly due to photodegradation of metsulfuron-methyl.

Thus, it may be concluded that post-emergence application of metsulfuron-methyl 4 g/ha for weed management could be considered as safe, as the residues were below maximum residue limits.

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Pre- and post-emergence herbicides effect on growth, nodulation and productivity of greengram

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ABSTRACT

A field experiment was conducted during *Kharif* season to study the efficacy of different pre- and post-emergence herbicides for weed management in greengram. Pre-emergence (PE) application of pendimethalin + imazethapyr at 0.75 kg/ha (pre-mix) effectively reduced both the density and dry matter of weeds whereas post-emergence (PoE) application of imazethapyr 10 SL at 55 g/ha significantly reduced *Cyperus rotundus*. All the PE and PoE herbicides significantly reduced the dry weight of weeds at 30 and 60 days after sowing (DAS) as compared to weedy check. The highest weed control efficiency was recorded in two hand weeding (90.2%), and was followed by pendimethalin + imazethapyr (pre-mix) 0.75 kg/ha applied as PE (86.8%). PoE herbicides (imazethapyr, imazamox+ imazethapyr and clodinafop-propargyl + aciflourfen-sodium) not only suppressed the crop growth, but also exhibited antagonistic effect on root nodulation. Significantly higher seed yields were recorded under two hand weeding and pendimethalin + imazethapyr at 0.75 kg/ha (PE). Two hand weeding also recorded the highest gross and net returns, and was followed by pendimethalin + imazethapyr (pre-mix) at 0.75 kg/ha (PE). Application of pendimethalin + imazethapyr at 0.75 kg/ha (PE) also gave the highest B:C ratio, and it was followed by two hand weeding. All the PoE herbicides fetched comparatively lower returns and B:C ratio.

INTRODUCTION

Greengram [*Vigna radiata* (L.) Wilczek] is an important pulse crop grown during both summer and *Kharif* (rainy) seasons in India. It occupied an area of 4.24 million hectares with a production of 2.03 million tonnes and productivity of 477 kg/ha in India during 2017-18 (Indiastat 2019). Weeds pose a serious threat to the productivity of greengram due to greater competition for nutrients, water, space and sunlight. Yield loss in greengram due to such competition may occur to the tune of 60-80% (Nandan *et al.* 2011, Kumar *et al.* 2017). Since weed infestation becomes more during rainy season, the rainy season crop gets infested with a large number of fast growing weeds. The critical period of weed competition in greengram is during first 30 days of sowing. Being a short duration crop, care should be taken on proper weed management to improve the productivity of greengram.

Pre-emergence herbicides like pendimethalin effectively control the grassy and broad-leaf weeds during early phase of crop growth. Post-emergence (PoE) application of imazethapyr has also been reported to provide effective weed control in greengram (Singh *et al.* 2014a, Singh *et al.* 2017). Combinations of PE and PoE herbicides or certain ready-mix formulations are commercially available which may be helpful to manage complex weed flora and reduce crop-weed competition.

Considering these facts in view, the present study was conducted to evaluate the effect of different PE and PoE herbicides on symbiosis, growth, phytotoxicity and productivity in greengram.

MATERIALS AND METHODS

A field experiment was conducted at Research Farm of Punjab Agricultural University, Ludhiana (30°54' N latitude, 75°48' E longitude and 247 m altitude), Punjab during *Kharif* 2016 and 2017 in a randomized complete block design with three replications. The soil of the experimental site was loamy sand, having pH 7.2, organic carbon 0.36%, available P 34.2 kg/ha and available K 195 kg/ha. A total of 217.5 mm (14 rainy days) and 219.4 mm (11 rainy days) rainfall was received during the crop season in 2016 and 2017, respectively. There were nine treatments (**Table 1**), including post-emergence (PoE) herbicides *viz.* imazethapyr 10 SL, imazamox 35 WG + imazethapyr 35 WG (pre-mix) and clodinafop propargyl 8% + aciflourfen sodium 16% (pre-mix) applied at 15-20 days after sowing (DAS); pre-emergence herbicides, *viz.* pendimethalin 30 EC and pendimethalin 30 EC + imazethapyr 2 EC (pre-mix) applied within 24 hours of sowing; two hand weeding (20 and 40 DAS); and weedy check. Herbicides were applied with knapsack sprayer fitted with flat fan nozzle using 500 L of water/ha. In case of hand weeding treatment, weeds were removed manually with the use of a *'Khurpa'* (hand spade). In weedy check plots, weeds were allowed to grow throughout the crop growing season.

After pre-sowing irrigation, the field was prepared at an optimum soil moisture and ploughed twice followed by planking. The varieties taken for the study were '*ML 818*' and '*ML 2056*' during 2016 and 2017, respectively. The crop was sown on 18 July, 2016 and 21 July, 2017 in rows of 30 cm apart using a seed rate of 20 kg/ha in the individual plot size of 7.0 × 4.5 m. The crop was harvested in first week of October during both the years.

Data on weed species count were recorded at 30 and 60 DAS from a randomly selected area, measuring 50 × 50 cm from each plot, and then converted as weed density in terms of no./m^2. After counting, all the weeds were oven-dried for taking dry weight of weeds (g/m^2) at 30 and 60 DAS. At harvest, weeds from the whole plot were harvested, dried and weighed (kg/ha). Weed control efficiency (WCE) was recorded at harvest and calculated by using the following formula:

$$\text{WCE (\%)} = \frac{X - Y}{X} \times 100$$

[Where, WCE= Weed control efficiency (%), X= Dry weight of weeds (kg/ha) in weedy check and Y= Dry weight of weeds (kg/ha) in treated plot]

Data on nodulation parameters, *viz.* number and dry weight of nodules were recorded at 40 DAS. Five plants in each plot were randomly selected to record the total number and dry weight of nodules, and the values were averaged to work out nodule number and dry weight/plant. Data on plant height, number of branches/plant and number of pods/plant were recorded at maturity from five plants selected randomly from each plot, and number of seeds/pod from randomly selected 20 pods. Biological yield and seed yield were recorded on the basis of whole plot area and expressed in t/ha. Harvest index (HI) was also calculated. The weight of 100 seeds was recorded from the economic produce of each plot. Gross return, net return as well as benefit:cost (B:C) ratio were worked out using prevailing prices of inputs and output. Two-year pooled data were subjected to analysis of variance (ANOVA) in a randomized complete block design as per standard procedure.

RESULTS AND DISCUSSION

Effect on weed parameters

The major weed flora at the experimental site (**Table 1**) comprised of *Cyperus rotundus* (purple nutsedge), *Eleucine aegyptiacum* (crow foot grass) and *Commelina benghalensis* (day flower). Of these, *C. rotundus* was the most dominant weed, followed by *E. aegyptiacum* and *C. benghalensis.* The highest weed density was recorded in weedy check at 30 and 60 DAS (**Table 1**). Application of pendimethalin 750 g/ha (PE) did not control *Cyperus rotundus*, which was, however, effectively controlled by either the PE application of pendimethalin + imazethapyr (pre-mix) 750 g/ha or the PoE application of imazethapyr 55 g/ha. Density of *Eleucine aegyptiacum* and *Commelina benghalensis* was increased at 60 DAS in comparison to 30 DAS, whereas that of *Cyperus rotundus* was reduced.

Two rounds of hand weeding recorded the lowest dry weight of weeds, and it was followed by pre-mix application of pendimethalin + imazethapyr at 750 g/ha as PE (**Table 1**). All the PE and PoE herbicides significantly reduced the dry weight of weeds at 30 and 60 DAS as compared to weedy check. There were reports on effective weed management with the PoE application of imazethapyr in soybean (Gare *et al.* 2016) and blackgram (Aggarwal *et al.* 2014). Reduction of weed dry weight with the application of pendimethalin was reported by several researchers (Singh 2011, Singh *et al.* 2017, Virk *et al.* 2018). Application of imazethapyr as PoE was reported to provide effective weed control in greengram (Singh *et al.* 2014a, Singh *et al.* 2015, Kumar *et al.* 2016), blackgram (Aggarwal *et al.* 2014) and lentil (Singh *et al.* 2014b).

Dry weight of weeds and weed control efficiency at harvest were significantly affected by different weed control treatments (**Table 2**). Weedy check recorded the highest dry weight of weeds, whereas it was the lowest under two rounds of hand weeding. Among the chemical treatments, pendimethalin + imazethapyr (pre-mix) at 750 g/ha recorded the lowest dry weight of weeds at harvest. The highest WCE was recorded with two hand weeding (90.2%), followed by pendimethalin + imazethapyr (pre-mix) as PE at 750 g/ha (86.8%). All the PoE herbicides recorded low WCE due to more occurrence of rainfall during early phase of crop growth which might have resulted in more flushes of weeds.

Effect on nodulation parameters

Number and dry weight of root nodules/plant at 40 DAS were significantly affected by different weed control treatments (**Table 2**). Two hand weedings recorded the highest number and dry weight of nodules/plant. PoE herbicides recorded lower number of nodules/plant (excepting imazamox + imzathapyr at 40 g/ha) and nodule dry weight/plant (excepting imazethapyr at 55 g/ha) in comparison to the PE herbicides and two hand weedings. Reduction in dry weight of plant might be due to phytotoxic effect of PoE herbicides on crop plants.

Antagonistic effect of PoE herbicides on number and dry weight of nodules/plant might be due to either phytotoxic effect on crop plants or adverse effect on nodule forming rhizobia. Application of imazethapyr at 25, 40 and 75 g/ha showed negative effect on different symbiotic parameters such as nodule number, nodule dry weight and leghaemoglobin content as compared to two hand weeding in greengram (Singh *et al*. 2015). Imazethapyr not only caused a significant reduction of rhizobial growth in a medium amended with it under *in vitro* condition but also showed inhibitory effect on symbiotic interaction in field studies in pigeonpea (Khanna *et al.* 2012). Ahemad and Khan (2010) also reported the negative effect of quizalofop-p-ethyl and clodinafop on the symbiosis in greengram plants, and the effect was more pronounced with the increase in herbicide dose. Application of PoE herbicide imazethapyr + imazamox significantly reduced the nodulation of greengram (Khairnar *et al*. 2014). Similarly, PoE application of imazethapyr (70 and 80 g/ha) or

Table 1. Effect of different weed control treatments on weed parameters in greengram at 30 and 60 DAS (pooled data of two years)

Treatment	30 DAS				60 DAS			
	Weed density (no./m^2)			Dry weight of weeds (g/m^2)	Weed density (no./m^2)			Dry weight of weeds (g/m^2)
	Cyperus rotundus	*Eleucine aegyptiacum*	*Commelina benghalenesis*		*Cyperus rotundus*	*Eleucine aegyptiacum*	*Commelina benghalenesis*	
Pendimethalin 750 g/ha (PE)	6.9 (47)	2.2 (5)	2.8 (7)	82	8.1 (66)	2.6 (7)	2.7 (7)	97
Pendimethalin + imazethapyr 750 g/ha (PE)	3.9 (15)	1.5 (2)	1.0 (0)	19	3.6 (12)	3.0 (9)	1.5 (2)	14
Imazethapyr 55 g/ha (PoE)	4.5 (20)	4.5 (20)	2.5 (6)	115	5.4 (29)	5.0 (25)	2.9 (8)	117
Imazamox + imazethapyr 40 g/ha (PoE)	7.0 (49)	4.8 (23)	2.3 (5)	97	6.4 (40)	4.9 (24)	2.6 (6)	111
Imazamox + imazethapyr 60 g/ha (PoE)	6.0 (36)	5.3 (30)	2.5 (6)	86	4.6 (22)	4.5 (21)	3.4 (11)	93
Clodinafop-propargyl+ aciflourfen-sodium 125 g/ha (PoE)	5.9 (35)	6.1 (37)	2.6 (7)	153	4.3 (18)	5.1 (27)	2.7 (7)	181
Clodinafop-propargyl + aciflourfen-sodium 187.5 g/ha (PoE)	5.5 (30)	5.1 (26)	2.7 (7)	112	4.9 (24)	5.3 (28)	2.4 (5)	129
Two hand weeding	2.8 (8)	2.7 (7)	1.0 (0)	6	3.8 (15)	2.3 (5)	1.2 (1)	10
Weedy check	9.0 (91)	7.9 (63)	3.8 (14)	238	9.5 (92)	6.9 (48)	3.7 (13)	323
LSD (p=0.05)	1.1	0.9	1.2	32	0.8	0.7	0.7	35

Original data on weed density are in parentheses and subjected to square root transformation ($\sqrt{x+0.5}$). PE: Pre-emergence, PoE: Post-emergence

Table 2. Effect of different weed control treatments on weed growth, weed control efficiency at harvest and nodulation parameters at 40 DAS in greengram (pooled data of two years)

Treatment	Weed dry weight (t/ha)	WCE (%)	Nodule no./plant	Nodule dry weight/plant (mg)	Plant dry weight (g)
Pendimethalin 750 g/ha (PE)	2.36	36.5	25.7	26.9	7.2
Pendimethalin + imazethapyr 750 g/ha (PE)	0.93	86.8	26.1	26.8	7.4
Imazethapyr 55 g/ha (PoE)	2.31	37.8	23.1	26.8	5.8
Imazamox + imazethapyr 40 g/ha (PoE)	2.95	16.8	27.9	21.2	6.1
Imazamox + imazethapyr 60 g/ha (PoE)	2.85	20.2	19.8	23.2	5.4
Clodinafop-propargyl + aciflourfen-sodium 125 g/ha (PoE)	2.57	31.9	21.9	24.6	6.0
Clodinafop-propargyl + aciflourfen-sodium 187.5 g/ha (PoE)	2.41	36.5	23.6	24.0	6.0
Two hand weeding	0.36	90.2	28.5	31.4	6.8
Weedy check	3.77	-	16.6	21.4	5.6
LSD (p=0.05)	0.24	6.3	3.6	3.4	1.0

imazethapyr + imazamox as ready-mix (80 g/ha) also posed their negative impact on nodule number and plant dry weight in greengram (Mishra *et al.* 2017).

Effect on crop growth parameters, yield attributes and yield

Different weed control treatments significantly influenced the plant height, branches/plant, pods/ plant and seeds/pod (**Table 3**). Two hand weedings recorded the highest plant height, branches/plant and pods/plant whereas PoE application of imazethapyr (55 g/ha) and imazamox + imazethapyr (40 and 60 g/ ha) recorded significantly lower plant height than the other herbicides. It might be due to some sorts of phytotoxic effect of the herbicides on plant growth. PoE herbicides imazethapyr, imazamox + imazethapyr and clodinafop-propargyl + aciflourfen sodium caused similar reduction in branches/plant as recorded in weedy check plots with intense crop-weed competition. Application of imazethapyr + imazamox reduced the growth attributes of greengram (Khairnar *et al.* 2014).

Two hand weedings recorded the highest number of pods/plant, and it was followed by pendimethalin + imazethapyr (pre-mix) at 750 g/ha. Similarly, number of seeds/pod was the highest under two rounds of hand weeding and pendimethalin + imazethapyr (750 g/ha). The number of pods/plant and seeds/pod were the lowest in weedy check. Higher number of pods/plant and seeds/pod in two hand weeding and pendimethalin + imazethapyr (pre-mix at 750 g/ha) could be due to better weed control (**Table 1**) under these treatments. However, 100-seed weight was not significantly affected by different weed control treatments.

Biological yield and seed yield were significantly affected by different weed control treatments (**Table 4**). Two hand weeding recorded the highest biological yield and seed yield, whereas these were the lowest under weedy check. Among the herbicidal treatments, application of pendimethalin + imazethapyr (pre-mix) at 750 g/ha recorded significantly higher seed yield than the others. Higher seed yield was attributed to the production of more number of pods/plant (**Table 3**), owing to better weed management (**Table 1**) as evidenced from reduced weed dry weight and higher WCE at harvest (**Table 2**). Application of imazamox + imazethapyr at 60 g/ha (PoE) recorded the highest HI, and it was followed by two hand weeding although the said herbicidal combination recorded low seed yield. Khairnar *et al.* (2014) also reported low seed yield of greengram with the use of imazethapyr + imazamox as compared to two hand weeding. All the weed control treatments recorded significantly higher HI than the weedy check.

Better plant growth, higher values of yield attributes and less crop-weed competition might be the reasons behind the higher seed yield of greengram under treatment of pendimethalin + imazethapyr (pre-mix at 750 g/ha). Increase in seed yield due to efficient weed management practices was also reported in greengram (Singh *et al.* 2015), blackgram (Singh *et al.* 2018) and soybean (Virk *et al.* 2018).

Effect on economics

Gross returns, net returns and B:C ratio were significantly affected by different weed control treatments (**Table 4**). Two hand weeding recorded the highest gross returns and net returns, and was followed by application of pendimethalin + imazethapyr (pre-mix) at 750 g/ha. Application of pendimethalin + imazethapyr (pre-mix) at 750 g/ha gave the highest B:C ratio, and was followed by two hand weeding. Two rounds of hand weeding and pendimethalin + imazethapyr at 750 g/ha proved to be more economical due to better B:C ratio as a result of effective weed management. All the PoE herbicides fetched lower gross and net returns as well as B:C ratio as compared to that of hand weeding and

Table 3. Effect of different weed control treatments on plant characters and yield attributes of greengram at harvest (pooled data of two years)

Treatment	Plant height (cm)	Branches/ plant	Pods/ plant	Seeds/ pod	100-seed weight (g)
Pendimethalin 750 g/ha (PE)	66.6	5.2	19.1	11.8	3.21
Pendimethalin + imazethapyr 750 g/ha (PE)	67.5	6.0	21.2	12.2	3.19
Imazethapyr 55 g/ha (PoE)	59.5	4.9	16.4	11.7	3.21
Imazamox + imazethapyr 40 g/ha (PoE)	60.7	4.2	15.3	11.8	3.10
Imazamox + imazethapyr 60 g/ha (PoE)	60.8	4.3	17.8	11.9	3.22
Clodinafop-propargyl+ aciflourfen-sodium 125 g/ha (PoE)	64.6	4.0	13.2	11.4	3.14
Clodinafop-propargyl+ aciflourfen-sodium187.5 g/ha (PoE)	65.6	4.0	12.8	11.6	3.20
Two hand weeding	68.2	6.1	22.1	12.2	3.20
Weedy check	66.1	4.2	9.7	11.2	3.26
LSD (p=0.05)	2.2	0.5	1.3	0.4	NS

Table 4. Effect of different weed control treatments on yield, harvest index and economics of greengram (pooled data of two years)

Treatment	Biological yield (t/ha)			Seed yield (t/ha)			Harvest index (%)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio
	2016	2017	Mean	2016	2017	Mean				
Pendimethalin 750 g/ha (PE)	3.41	3.24	3.33	0.81	0.72	0.77	23.2	42.98	22.10	2.06
Pendimethalin + imazethapyr 750 g/ha (PE)	4.02	5.47	4.75	0.91	1.17	1.04	22.0	58.25	36.12	2.63
Imazethapyr 55 g/ha (PoE)	3.92	3.06	3.49	0.85	0.54	0.70	19.8	39.05	18.68	1.92
Imazamox + imazethapyr 40 g/ha (PoE)	3.24	2.92	3.08	0.76	0.58	0.67	21.8	37.59	16.72	1.80
Imazamox + imazethapyr 60 g/ha (PoE)	3.44	2.94	3.19	0.93	0.65	0.79	24.8	44.50	23.13	2.08
Clodinafop-propargyl+ aciflourfen-sodium 125 g/ha (PoE)	3.23	2.91	3.07	0.65	0.60	0.63	20.5	35.09	14.47	1.70
Clodinafop-propargyl+ aciflourfen-sodium187.5 g/ha (PoE)	3.13	2.88	3.01	0.52	0.61	0.56	18.9	31.56	10.44	1.49
Two hand weeding	4.76	5.74	5.25	1.08	1.22	1.15	22.1	64.37	37.24	2.37
Weedy check	3.06	1.91	2.49	0.48	0.20	0.34	13.3	19.01	-0.11	0.99
LSD (p=0.05)	0.54	0.41	0.33	0.11	0.09	0.07	1.7	4.06	4.06	0.19

pendimethalin + imazethapyr (pre-mix) at 0.75 kg/ha. Lower monetary returns were also earlier reported with imazethapyr + imazamox in greengram (Khairnar *et al.* 2014).

It was concluded that PE application of pendimethalin + imazethapyr (pre-mix) at 750 g/ha can effectively control the major weeds and provide higher net return and B:C ratio in greengram.

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Efficacy of herbicides on weeds and yield of greengram

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ABSTRACT

The field experiments were conducted during *Kharif* 2016 and 2017 at Research Farm, College of Agriculture, RVSKVV, Gwalior (M.P.) to study the effective herbicide/combination of herbicides to control the problematic weeds in greengram (*Vigna radiata*). The experiments were laid out with ten treatments, *viz*. quizalofop-p-ethyl 50, 75 and 100 g/ha PoE, fenoxaprop-p-ethyl 100 g/ha PoE, pendimethalin 1000 g/ha pre-emergence (PE), pendimethalin + imazethapyr (RM) 750 and 1000 g/ha PE, imazethapyr + imazamox (RM) 80 g/ha PoE, two hand weeding at 20 and 40 DAS and weedy check in a randomized block design. The combination of imazethapyr + imazamox (RM) 80 g/ha applied as post-emergence was found to be very efficient in controlling the dominant grassy as well as broad-leaved weeds and produced maximum seed yield (993 kg/ha), and was at par with two hand weedings at 20 and 40 DAS (983 kg/ha) and combination of pendimethalin + imazethapyr 750 g/ha and 1000 g/ha PE (844 and 758 kg/ha, respectively). Application of imazethapyr + imazamox (RM) 80 g/ha PoE resulted in the highest B:C ratio (3.03), and net returns, *fb* pendimethalin + imazethapyr 750 g/ha PE and two hand weeding at 20 and 40 DAS.

INTRODUCTION

Greengram (*Vigna radiata* L.) is not very competitive against weeds. The loss of yield due to weeds ranges from 30 to 85% (Raman and Krishnamoorthy 2005, Dungarwal *et al*. 2003 and Mirjha *et al*. 2013). Therefore, proper weed management is essential to ensure good crop growth, especially in early stages. Among different methods of weed control, the chemical method is becoming popular among farmers because of increasing labour costs. The available pre- and post-emergence herbicides, *viz*. pendimethalin, oxyfluorfen, fenoxaprop-p-ethyl and quizalofop-ethyl are able to check the emergence and growth of annual grasses and broad-leaved weeds. Imazethapyr, a broad-spectrum herbicide, has soil and foliar activity that allows flexibility in its application timing and has low mammalian toxicity (Gupta *et al.* 2017, Tamang *et al.* 2015). Chhodavadia *et al.* (2013) reported that post-emergence application of imazethapyr 25 g/ha had no adverse effect on growth characters and resulted statistically similar grain yield to that of twice hand weeding (20 and 40 DAS). Pendimethalin is basically pre-emergence herbicide. In rain fed condition, if weeds have not yet germinated, this herbicide may be effective when applied after first shower.

The present study was taken to determine the efficacy of herbicides on problematic weeds and their impact on yield of greengram.

MATERIALS AND METHOD

Field experiments were conducted during *Kharif* 2016 and 2017 at Research Farm, College of Agriculture, Gwalior (M.P.) of 412 m altitude from sea level, 79^0 54'E longitude and 23^0 10'N latitude to find out the efficacy of herbicides on problematic weeds and their impact on yield of greengram. The soil was sandy clay loam in texture, low in available nitrogen (195 kg/ha), medium in phosphorus (13 kg/ha) and potassium (204 kg/ha) with pH 7.7 and EC 0.41 dS/m. The 10 treatments, *viz*. quizalofop-p-ethyl 50, 75 and 100 g/ha PoE, fenoxaprop-p-ethyl 100 g/ha PoE, pendimethalin 1000 g/ha PE, pendimethalin + imazethapyr (RM) 750 and 1000 g/ha pre-emergence (PE), imazethapyr + imazamox (RM) 80 g/ha PoE, two hand weeding at 20 and 40 DAS and weedy check were replicated thrice in a completely RBD. Greengram variety '*TJM-3*' was sown on 19^{th} and 16^{th} July with the seed rate of 18 kg/ha maintaining row to row spacing of 40 cm and harvested on 3^{rd} and 5^{th} October, in 2016 and 2017, respectively. The recommended dose of fertilizer 20:50:20 NPK kg/ha was applied during both the years. Pre-emergence herbicides were applied within 48 hours of sowing and post-emergence herbicides were applied on 20th day after sowing. Both the herbicides were applied with the help of flat fan nozzle and knapsack battery sprayer with a spray volume of 600 litre water/ha. Observations on weeds were recorded with the help of quadrate 1.0 m^2 placed randomly in each plot at 40 DAS and same were dried in the oven at the temperature 60-80 ^{0}C. Crop yield was recorded at harvest stage. Weed control efficiency and economics of different weed control treatments were also worked out.

The average rainfall of the state was 750 mm. Out of that, 590 mm was received during *Kharif* 2016 and 580 mm during *Kharif* 2017. Although the distribution of rainfall was erratic but good amount of rainfall was received during both the years. The temperature ranged from 13.5 ^{0}C to 44 ^{0}C during both the years.

RESULTS AND DISCUSSION

Effect on weeds

The major weed flora observed in an experimental site during *Kharif* 2016 and 2017 were *Cyperus rotundus* (55.45%), *Echinochloa crus-galli* (5.45%), *Setaria glauca* (1.97%), *Acrachne racemes* (12.78%), *Cynodon dactylon* (0.80%), and *Erragrostis* spp. (0.62%) as grasses. *Celosia argentia* (1.79%), *Phyllanthus niruri* (1.65%), *Commelina benghalensis* (5.9%) and *Digera arvensis* (13.58%), were observed as major broad-leaved weeds (BLWs). Among them, *Cyperus rotundus* was the most problematic weed and accounted for 55.45% of the total weed population during both the years (**Table 1**). At 40 DAS, weedy check recorded the highest weed density of *Cyperus rotundus* and *Digera arvensis* whereas hand weeding recorded the lowest number of weeds *fb* post-emergence herbicide of imazethapyr + imazamox (RM) 80 g/ha. Density and dry weight of weeds were significantly affected by weed management practices **(Table 1-3)**. Population of all weeds was significantly reduced under the influence of two hand weeding at 20 and 40 DAS.

During both the years, combination of post-emergence herbicides, imazethapyr+ imazamox (RM) 80 g/ha controlled the narrow and broad-leaved weeds more effectively as compare to the combination of pre-emergence with post-emergence herbicide pendimethalin + imazethapyr (RM) 750 g/ha PE and 1000 g/ha. Although the application of pendimethalin + imazethapyr (RM) 1000 g/ha was at par with 750 g/ha as PE to control the broad-leaved weeds *viz. Celosia argentia*, *Phyllenthus niruri* and *Commelina benghalensis*. Quizalofop-p-ethyl (50, 75 and 100 g/ha PoE) was found effective in controlling the *Cyperus rotundus* when applied at higher dose (100 g/ha).

The dry matter of weeds was the highest in weedy check and the lowest in two hand weeding, which was at par with application of post-emergence herbicide, imazethapyr + imazamox (RM) 80 g/ha in 2017 but higher in 2016 **(Table 2)**. Imazethapyr + imazamox have been reported to provide effective control of grassy weeds in green-gram (Singh *et al*. 2014) and (Singh *et al*. 2015).

Table 1. Population of narrow-leaved weeds/m^2 as influenced by weed management practices at 40 DAS

Treatment	*Cyperus rotundus*			*Echinochloa crus-galli*			*Setaria glauca*			*Acrachne racemosa*	*Cynodon dactylon*	*Eragrostis* spp.
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2017	2017	2016
Quizalofop-p-ethyl 50 g/ha PoE	10.96 (119.7)	10.62 (112.3)	10.79 (116.0)	1.86 (3.00)	3.08 (9.00)	2.47 (6.0)	1.22 (1.00)	1.00 (0.67)	1.11 (0.83)	1.76 (2.67)	1.17 (1.00)	1.58 (2.00)
Quizalofop-p-ethyl 75 g/ha PoE	10.21 (107.0)	11.00 (123.3)	10.61 (115.7)	1.34 (1.33)	4.39 (20.33)	2.87 (10.8)	1.05 (0.67)	1.68 (2.33)	1.36 (1.50)	2.85 (7.67)	1.17 (1.00)	1.46 (1.67)
Quizalofop-p-ethyl 100 g/ha PoE	9.03 (83.7)	10.99 (153.3)	10.01 (118.5)	1.34 (1.33)	4.56 (20.67)	2.95 (11.0)	1.05 (0.67)	1.95 (3.33)	1.50 (2.00)	4.30 (18.00)	1.56 (2.00)	1.58 (2.00)
Fenoxaprop-p-ethyl 100 g/ha PoE	8.18 (71.7)	13.73 (190.3)	10.96 (131.0)	2.11 (4.00)	5.92 (34.67)	4.02 (19.3)	1.22 (1.00)	3.03 (8.67)	2.13 (4.83)	5.08 (25.33)	1.58 (2.00)	1.68 (2.33)
Pendimethalin 1000 g/ha PE	9.29 (86.7)	8.83 (79.3)	9.06 (83.0)	2.12 (4.00)	2.03 (3.67)	2.08 (3.8)	1.34 (1.33)	0.71 (0)	1.03 (0.67)	1.00 (0.67)	1.05 (0.67)	1.68 (2.33)
Pendimethalin + imazethapyr (RM) 750 g/ha PE	9.09 (82.7)	6.17 (39.3)	7.63 (61.0)	1.17 (1.00)	0.71 (0)	0.94 (0.5)	1.05 (0.67)	0.71 (0)	0.88 (0.33)	0.71 (0)	0.71 (0)	1.34 (1.33)
Pendimethalin + imazethapyr (RM) 1000 g/ha PE	7.36 (55.7)	8.64 (74.7)	8.00 (65.2)	1.05 (0.67)	0.71 (0)	0.88 (0.3)	1.05 (0.67)	0.71 (0)	0.88 (0.33)	0.71 (0)	0.71 (0)	1.17 (1.00)
Imazethapyr + imazamox (RM) 80 g/haPoE	6.30 (39.3)	4.83 (23.3)	5.56 (31.3)	1.05 (0.67)	0.71 (0)	0.88 (0.3)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.88 (0.33)
2 HW at 20 and 40 DAS	5.62 (31.3)	0.71 (0)	3.16 (15.7)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
Weedy check	12.28 (150.3)	16.16 (262.0)	14.22 (206.7)	2.27 (4.67)	6.12 (37.00)	6.94 (20.8)	1.87 (3.00)	3.49 (11.67)	2.68 (7.33)	1.69 (47.67)	1.87 (3.00)	1.68 (2.33)
LSD (p=0.05)	2.58	4.12	4.86	0.42	0.97	0.37	0.34	0.32	0.47	0.37	0.37	0.377

Original data were subjected to square root $\sqrt{x+0.5}$ transformation and presented in parentheses

Two hand weeding recorded the highest weed control efficiency (94.61%) *fb* imazethapyr + imazamox (RM) 80 g/ha (86.86%), pendimethalin + imazethapyr (RM) 750 g/ha (77.28%) and 1000 g/ha PE (75.64%) respectively due to lower dry matter of weeds.

Effect on crop

Weed control treatments significantly influenced the yield of green-gram (**Table 4**). On the basis of pooled analysis the yield of green-gram was superior in the case of imazethapyr + imazamox (RM) 80 g/ha and it was at par with two hand weeding *fb* pendimethalin+ imazethapyr (RM) 750 g/ha and pendimethalin + imazethapyr (RM) 1000 g/ha treatment. Similarly imazethapyr + imazamox (RM) 80 g/ha *fb* two hand weeding registered the highest biological yield which was significantly higher than other treatments as pooled analysis. (**Table 5**).

Economics

Application of imazethapyr + imazamox (RM) 80 g/ha PoE was proved to be economically the best weed management treatment with the maximum net returns ` 43,401/ha *fb* two hand weeding (` 38,906/ ha) and pendimethalin + imazethapyr 750 g/ha PE (` 34,512/ha). However, the maximum B:C ratio of 3.03 was found in imazethapyr + imazamox (RM) 80 g/ha PoE *fb* pendimethalin + imazethapyr 750 g/ha PE (2.56) and two hand weeding (2.48). The minimum net returns (` 4,917/ha) was recorded under weedy check with B:C ratio of 1.25 **(Table 5)**.

Weed persistence and herbicide efficiency indices

Weed persistence index (WPI) and herbicide efficiency index (HEI) express the tolerance of weeds to different herbicidal treatments as well as their efficacy to eradicate the weeds **(Table 3**). Among different pre- and post-emergence herbicides,

Table 2. Population of broad-leaved weeds /m^2 as influenced by weed management practices at 40 DAS

Treatment	*Celosia argentia*			*Phyllenthus niruri*			*Commelina benghalensis*			*Digera arvensis*		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
Quizalofop-p-ethyl 50 g/ha PoE	2.12	2.41	2.27	1.58	2.34	1.96	2.73	4.41	3.57	3.18	6.28	4.73
	(4.00)	(5.33)	(4.67)	(2.00	(5.00	(3.50	(7.00	(19.00	(13.00)	(9.67)	(39.00)	(24.33)
Quizalofop-p-ethyl 75 g/ha PoE	1.77	2.73	2.25	1.34	2.68	2.01	2.60	4.95	3.78	3.08	6.84	4.96
	(2.67)	(7.00)	(4.83)	(1.33)	(6.67)	(4.00)	(6.33)	(24.00)	(15.17)	(9.00)	(46.33)	(27.67)
Quizalofop-p-ethyl 100 g/ha PoE	1.56	3.13	2.35	1.34	2.85	2.10	2.54	4.98	3.76	2.34	7.78	5.06
	(2.00)	(9.33)	(5.67)	(1.33)	(7.67)	(4.50)	(6.00)	(24.33)	(15.17)	(5.00)	(61.00)	(33.00)
Fenoxaprop-p-ethyl 100 g/ha PoE	1.34	2.86	2.10	1.34	2.97	2.16	1.95	5.66	3.81	2.34	8.01	5.17
	(1.33)	(7.67)	(4.50)	(1.33)	(8.33)	(4.83)	(3.33)	(31.67)	(17.50)	(5.00)	(63.67)	(34.33)
Pendimethalin 1000 g/ha PE	1.34	1.64	1.49	1.22	1.76	1.49	1.86	4.34	3.10	1.86	4.37	3.11
	(1.33)	(2.67)	(2.00)	(1.00)	(2.67)	(1.83)	(3.00)	(18.33)	(10.67)	(3.00)	(18.67)	(10.83)
Pendimethalin + imazethapyr (RM) 750 g/ha PE	1.05	1.17	1.11	0.88	1.39	1.13	1.64	3.44	2.54	1.68	3.29	2.48
	(0.67)	(1.00)	(0.83)	(0.33)	(1.67)	(1.00)	(2.33)	(11.33)	(6.83)	(2.33)	(10.33)	(6.33)
Pendimethalin + imazethapyr (RM) 1000 g/ha PE	0.88	1.27	1.07	0.71	1.58	1.14	1.46	4.10	2.78	1.17	3.81	2.49
	(0.33)	(1.33)	(0.83)	(0)	(2.00)	(1.00)	(1.67)	(16.33)	(9.00)	(1.00)	(14.00)	(7.50)
Imazethapyr + imazamox (RM) 80 g/haPoE	0.71	1.05	0.88	0.71	1.34	1.03	1.05	3.29	2.17	0.71	2.91	1.81
	(0)	(0.67)	(0.33)	(0)	(1.33)	(0.67)	(0.67)	(10.33)	(5.50)	(0)	(8.00)	(4.00)
2 HW at 20 and 40 DAS	0.71	1.05	0.88	0.71	1.05	0.88	0.71	1.34	1.03	0.71	1.34	1.03
	(0)	(0.67)	(0.33)	(0)	(0.67)	(0.33)	(0)	(1.33)	(0.67)	(0)	(1.33)	(0.67)
Weedy check	2.27	3.03	2.65	1.68	3.24	2.46	3.19	5.90	4.54	3.48	9.40	6.44
	(4.67)	(8.67)	(6.67)	(2.33)	(10.0)	(6.17)	(9.67)	(34.33)	(22.00)	(11.67)	(88.00)	(49.83)
LSD (p=0.05)	0.347	0.622	0.712	0.275	0.447	0.525	0.391	0.386	0.549	0.387	0.765	0.858

Original data were subjected to square root $\sqrt{x+0.5}$ transformation and presented in parentheses

Table 3. Dry weight of weeds and weed control efficiency as influenced by weed management practices at 40 DAS

Treatment	Dry weight of weeds (g/m^2)			WCE (%)
	2016	2017	Pooled	
Quizalofop-p-ethyl 50 g/haPoE	70.33	63.73	67.03	52.89
Quizalofop-p-ethyl 75 g/haPoE	67.33	81.07	74.20	47.86
Quizalofop-p-ethyl 100 g/haPoE	47.33	101.47	74.40	47.72
Fenoxaprop-p-ethyl 100 g/haPoE	59.33	119.60	89.47	37.13
Pendimethalin 1000 g/ha PE	59.33	58.13	58.73	58.73
Pendimethalin + imazethapyr (RM) 750 g/haPE	47.33	17.33	32.33	77.28
Pendimethalin + imazethapyr (RM) 1000 g/ha PE	46.33	23.00	34.67	75.64
Imazethapyr + imazamox (RM) 80 g/haPoE	27.67	9.73	18.70	86.86
2 HW at 20 and 40 DAS	12.67	2.67	7.67	94.61
Weedy check	97.00	187.60	142.30	-
LSD (p=0.05)	6.684	9.578	11.680	-

Table 4. Biological yield, grain yield, herbicide efficiency index (HEI) and weed persistence index (WPI) of greengram as influenced by weed management practices

Treatment	Biological yield (t/ha)			Grain yield (t/ha)			Herbicide efficiency index			Weed persistence index		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
Quizalofop-p-ethyl 50 g/ha PoE	1.75	1.21	5.24	0.57	0.44	0.50	0.53	0.22	0.33	0.76	0.40	0.52
Quizalofop-p-ethyl 75 g/ha PoE	1.89	1.36	5.69	0.68	0.49	0.59	0.95	0.28	0.50	0.75	0.49	0.58
Quizalofop-p-ethyl 100 g/ha PoE	1.70	1.27	5.10	0.54	0.46	0.50	0.63	0.17	0.29	0.56	0.59	0.59
Fenoxaprop-p-ethyl 100 g/ha PoE	1.91	1.35	5.74	0.64	0.49	0.56	0.92	0.18	0.37	0.73	0.66	0.69
Pendimethalin 1000 g/ha PE	1.99	1.84	5.98	0.70	0.67	0.69	1.19	0.84	0.95	0.71	0.41	0.51
Pendimethalin + imazethapyr (RM) 750 g/ha PE	2.41	2.38	7.24	0.82	0.86	0.84	2.13	4.54	2.62	0.60	0.14	0.31
Pendimethalin + imazethapyr (RM) 1000 g/ha PE	2.18	2.12	6.55	0.75	0.77	0.76	1.76	2.79	1.99	0.62	0.17	0.32
Imazethapyr + imazamox (RM) 80 g/ha PoE	2.81	2.79	8.44	0.97	1.01	0.99	4.96	10.41	5.98	0.40	0.09	0.20
2 HW at 20 and 40 DAS	2.64	2.94	7.94	0.90	1.07	0.98	9.39	41.15	14.36	0.20	0.07	0.13
Weedy check	1.16	0.90	3.47	0.42	0.35	0.38	-	-	-	-	-	-
LSD (p=0.05)	0.65	0.71	0.97	0.17	0.19	0.25	-	-	-	-	-	-

Table 5. Economics of green-gram as influenced by weed management practices

Treatment	Total cost of cultivation (x10^3 `/ha)			Gross returns (x10^3 `/ha			Net returns (x10^3 `/ha)			B:C Ratio		
	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled	2016	2017	Pooled
Quizalofop-p-ethyl 50 g/haPoE	19.77	23.60	21.68	36.50	29.48	32.99	16.73	5.88	11.30	1.85	1.25	1.52
Quizalofop-p-ethyl 75 g/haPoE	20.57	24.68	22.62	43.00	33.07	38.04	22.43	8.39	15.41	2.09	1.34	1.68
Quizalofop-p-ethyl 100 g/haPoE	21.37	25.64	23.50	34.55	30.84	32.69	13.18	5.20	9.19	1.62	1.20	1.39
Fenoxaprop-p-ethyl 100 g/haPoE	19.67	23.60	21.63	40.78	32.76	36.77	21.11	9.16	15.13	2.07	1.39	1.70
Pendimethalin 1000 g/ha PE	18.93	22.70	20.81	44.82	44.58	44.70	25.89	21.88	23.88	2.37	1.96	2.15
Pendimethalin + imazethapyr (RM) 750 g/ha PE	18.78	22.50	20.64	52.62	57.68	55.15	33.84	35.18	34.51	2.80	2.56	2.67
Pendimethalin + imazethapyr (RM) 1000 g/ha PE	18.98	22.77	20.87	47.69	51.62	49.65	28.71	28.85	28.78	2.51	2.27	2.38
Imazethapyr + imazamox (RM) 80 g/ha PoE	19.52	23.30	21.41	62.01	67.61	64.81	42.49	44.31	43.40	3.18	2.90	3.03
2 HW at 20 and 40 DAS	22.06	28.78	25.42	57.37	71.28	64.33	35.31	42.50	38.91	2.60	2.48	2.53
Weedy check	18.17	21.80	19.99	26.50	23.31	24.90	8.33	1.50	4.92	1.46	1.07	1.25

application of post-emergence herbicide imazethapyr + imazamox 80 g/ha was recorded the lowest WPI (0.20%) *fb* pendimethalin + imazethapyr applied 750 g/ha and it was at par with its higher dose of 1000 g/ha. Among all treatments, the highest WPI was recorded with fenoxaprop-p-ethyl 100 g/ha PoE *fb* post-emergence application of quizalofop-p-ethyl 100 g/ha, which was at par with its lower dose of 75 g/ha. Regarding HEI, application of post- emergence herbicide of imazethapyr + imazamox 80 g/ha produced higher HEI (5.98%) than all other herbicidal treatments *fb* pendimethalin + imazethapyr applied 750 g/ha. However, twice hand weeding (20 and 40 DAS) proved to be superior to all the herbicidal treatments.

On the basis of pooled data, it was concluded that post-emergence application of imazethapyr + imazamox (RM) 80 g/ha produced maximum seed yield (993 kg/ha) *fb* two hand weeding at 20 and 40 DAS (983 kg/ha) and pre-emergence application of pendimethalin + imazethapyr 750 g/ha (844 kg/ha).

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Biology and large scale demonstration for management of *Orobanche aegyptiaca* in mustard

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ABSTRACT

Field experiments to study the efficacy of neem cake, soil drenching of metalaxyl, post-emergence application of glyphosate at very low concentrations alone and in combination with 1% solution of ammonium sulphate and 125% of recommended fertility, were conducted at village Ganghala (Bhiwani) during *Rabi* seasons of 2014-15 and village Bidhwan (Bhiwani) during 2015-16. Feasibility of adoption of results of studies conducted earlier on use of glyphosate 25 g/ha at 30 DAS and 50 g/ha at 55 DAS is being demonstrated by multi location field trials through farmers participatory approach in different parts of state during 2010-2016. Neem cake 400 kg/ha *fb* pendimethalin (PPI) at 0.75 kg/ha *fb* HW at 60 DAS did not prove effective in minimizing density of *Orobanche*. Post-emergence application of glyphosate at 25 and 50 g/ha at 25 and 55 DAS, respectively showed promising results with 75-95% control of this weed in experimental field and 76.5% on large scale demonstrations at farmers' fields. Biotype from Ganghala (Bhiwani) was found to be most robust biotype with 5840 seeds per capsule.

INTRODUCTION

Parasitization of *Orobanche* in broad-leaf crops especially that belonging to brassicaceae and solanaceae family is a serious problem globally. *Orobanche* is a serious weed of mustard, tomato, brinjal, tobacco, potato and other commercial crops in some regions throughout the country. It is a phanerogamic, obligate, troublesome holo root parasite that lack chlorophyll (Baccarini and Melandri 1967, Saghir *et al*. 1973) and obtain carbon, nutrients, and water through haustoria which connect the parasite with the host vascular system. (Dorr and Kollmann 1976, Press *et al*. 1986). The diversion of these substances to the parasitic weed causes moisture and assimilate starvation, host plant stress and growth inhibition leading to extensive reduction in crop yield and quality in infested fields. Depending upon the extent of infestation, environmental factors, soil fertility, and the crops' response, damage from *Orobanche* can range from zero to complete crop failure (Dhanapal *et al*. 1996). This parasitic weed has the tendency to proliferate well in coarse textured soils with high pH, low nitrogen status and poor water holding capacity. In Haryana state, infestation of obnoxious weed *Orobanche aegyptiaca* has been observed in mustard fields in 0.25 mha area in south-western part of the state. However, the increasing infestation of *Orobanche* over the years have seriously impacted mustard cultivation and threatened the livelihood security of farmers of the region

Intensive research was undertaken under the All India Coordinated Research Programme on Weed Management at Hisar centre for more than a decade using farmers' participatory approaches. Herbicide screening trials were undertaken using chemicals at different rates, time and method of application. Pre-emergence, Pre- plant incorporation (PPI) or herbigation of trifluralin along with hoeing proved ineffective in minimizing the density of this weed. Post-emergence application of glyphosate at normal doses, kerosene oil and paraquat caused toxicity to mustard crop. Change in the genotype or sources of nutrient supply did not prove effective in minimizing density of this weed. After some initial positive response on tolerance of mustard plants and significant reduction in *Orobanche* shoots with application of glyphosate, research work was straightened to standardize the dose, timing and number of sprays and also associated agronomic practices. It was realized that a slight suppression in mustard growth occurs with glyphosate application at some places. This difference in selectivity can be genetically inherited. Keeping in view, studies were undertaken to study the biology of *Orobanche* of seeds collected from different locations and effectiveness of different treatments in conjunction with glyphosate.

MATERIALS AND METHODS

The experiment on biology was undertaken in screen house of CCS HAU Hisar. Seeds of *Orobanche* collected from Bidhwan (Bhiwani), Obera (Bhiwani), Budhera (Bhiwnai) and Hasan (Bhiwani) during 2012-13 and Gangala (Bhiwani), Juglan (Hisar) Gignau (Bhiwani) and dry land area of HAU, Hisar during *Rabi* 2013-14 were sown in earthen pots of 1x1 ft diameter filled with loamy sand soil and FYM. After 15 days of germination, 10 plants per pot were maintained and observations on days to appearance of *Orobanche*, fresh and dry weight/panicle, number of shoots/panicle flower initiation (days after emergence) number of capsules/shoot, capsule weight/panicle and number of seeds/capsule were recorded.

In field experiment, studies were conducted to observe the effectiveness of neem cake alone or in conjunction with pendimethalin at 200 and 400 kg/ha, glyphosate at 25 and 50 g/ha at 30 and 55 DAS respectively, alone and in combination with 1% solution of ammonium sulphate [$(NH_4)_2So_4$], *Trichoderma viride* at 5.0 kg/ha before sowing, glyphosate alone at 50 g/ha at 40 DAS were compared with three hand weedings at 30, 60 and 90 DAS and untreated check. Present experiment was conducted at the farm of Sh. Rai Singh of village Bidhwan Distt. Bhiwani situated at latitude of N 28 ^{o} 45' 772" and E 075 ^{o} 36' 526 ''. Variety '*RH-0749*' was planted on 22th November 2013 in randomized block design in a plot size of 25 x 6 m^2 with three replications. Field selected was heavily infested with *Orobanche aegyptiaca* during previous years. Various treatments were imposed as per schedule as given in **Table 2** and **3**. Data on number of *Orobanche* panicles/m^2, per cent visual control of *Orobanche* was recorded at 120 days after sowing on 0-100 scale. The technology on use of glyphosate was validated through a large number of multi-locational trials in different districts of Hisar, Bhiwani and Mahendergarh between 2010 and 2017. A total of 758 demonstrations were conducted in mustard growing areas of Haryana state covering 1781 ha area.

RESULTS AND DISCUSSION

Biology of *Orobanche*: During 2012, *Orobanche* panicles appeared above soil on an average 55-60 days after sowing of mustard. Fresh weight of shoot was in the range of 30.9-40.2 g/plant as against 3.56-4.60 g/plant dry shoot weight. Violet cream colored flowers started to appear 10-12 days after panicle emergence of *Orobanche*. The capsule number per shoot varied from 40-46 while capsule weight was observed to be in the range of 0.084-00.132 g. The number of seeds per capsule varied from 3690-5625. Among all the biotypes, it was observed that biotypes of Bidhwan were stronger as compared to others. During 2013-14, *Orobanche* panicles appeared above soil on an average 45-54 days after sowing of mustard. Fresh weight of shoot was in the range of 34.9-42.5 g/plant as against 4.2-5.20 g/plant dry weight of shoot. Violet cream colored flowers started to appear 11-13 days after panicle emergence of *Orobanche*. The capsule number per shoot varied from 38-45 while capsule weight was observed to be in the range of 0.094-0.124 g. The number of seeds per capsule varied 3870-5840. Biotype from Gangala was stronger as compared to others. This collaborates the finding of Punia *et al.* (2018).

Effect of different weed control measures on *Orobanche* population and seed yield of mustard

During both the years, pendimethalin alone or in combination with neem cake did not prove useful in minimizing population of *Orobanche aegyptiaca*. Use of *Trichoderma viridae* at 5 kg/ha and neem cake at 200 and 400 kg/ha did not cause any inhibition of *Orobanche* emergence. Glyphosate application at 25 g/ha at 30 DAS and 50 g/ha at 55 DAS alone or with 1% with $(NH_4)_2So_4$ provided good (80-95%) and (75-80%) control of *Orobanche* up to 120 days after sowing during 2012-13 and 2013-14, respectively (**Table 2** and **3**). Although use of glyphosate alone at 50 g/ha at 40 DAS provided 60-80% control of *Orobanche* but 10% crop suppression in terms of chlorosis and necrosis was observed resulting in poor yield. Maximum seed yield of mustard (1.82 t/ha during 2012-13 and 1.81 t/ha during 2013-14) was observed with use of glyphosate 25 g/ha at 30 DAS and 50 g/ha at 55 DAS which was at par with all glyphosate treatments. Presence of *Orobanche* throughout crop season caused 29.4 and 20.4% reduction in seed yield of mustard during 2012-13 and 2013-14, respectively as compared to use of glyphosate 25 g/ha at 25 DAS and 50 g/ha at 55 DAS (RP).

Similar findings on the control of *Orobanche* in mustard through glyphosate application were also reported by the scientists at Gwalior and Bikaner (DWSR 2009, Punia *et al.* 2012 and Punia *et.al*. 2016).

Table 1. Various phenological parameters of *Orobanche* in mustard (2012-13 and 2013-14)

Characteristic	2012-13				2013-14			
	Bidhwan	Obera	Budhera	Hasan	Gangala	Juglan	Gignau	Hisar
Days to appearance of panicle	55	52	60	58	50	48	45	54
Fresh wt./plant (g)	40.2	36.6	35.8	30.9	42.5	40.6	38.2	34.9
Dry wt./plant (g)	4.60	3.86	3.60	3.56	5.20	4.98	4.02	4.2
No of shoots/plant	4.5	2.6	3.5	2.5	5.5	4.4	3.9	2.7
Flower initiation (days after emergence)	12	10	11	12	12	11	11	13
Capsules (no./shoot)	46	40	45	42	45	42	38	40
Capsule wt./plant(g)	0.132	0.084	0.098	0.013	0.124	0.110	0.094	0.095
No. of seeds/capsule	5625	4580	3690	3944	5840	4472	3870	4150

Table 2. Effect of different weed control measures on *Orobanche* population and seed yield of mustard (2012-13)

Treatment	*Orobanche* panicles /m^2		Visual control (%)	Seed yield (t/ha)	Remarks
	70 DAS	120 DAS			
Pendimethalin 1.0 kg/ha *fb* HW at 60 DAS	4	17	0	1.42	10% poor germination
Neem cake 200 kg/ha in furrow *fb* HW at 60 DAS	2	14	0	1.38	
Neem cake 200 kg/ha in furrow and pendimethalin 0.5 kg/ha *fb* HW at 60 DAS	3	19	0	1.46	
Neem cake 400 kg/ha in furrow *fb* HW at 60 DAS	4	11	0	1.48	
Neem cake 400 kg/ha in furrow *fb* pendimethalin 0.5 kg/ha *fb* HW at 60 DAS	0	17	0	1.52	
Glyphosate 25 and 50 g/ha at 30 and 55 DAS	0	0.66	95	1.82	
Glyphosate 25 and 50 g/ha at 30 and 55 DAS with 1% $(NH_4)_2So_4$	0	1	90	1.74	
Glyphosate 25 and 50 g/ha at 30 and 55 DAS(RP)	0	0	100	1.76	
Glyphosate 25 g/ha at 30 DAS and 50 g/ha at 40 DAS	0	2	90	1.76	15 % crop suppression
Glyphosate 50 g/ha at 40 DAS	0	4	80	1.74	10 % crop suppression
HW at 30,60 and 90 DAS	4	22	0	1.60	
Trichoderma viride at 5 kg/ha before sowing	2	17	0	1.65	
Weedy check	4	21	-	1.44	
LSD (p=0.05)		2.4	-	0.01	

Table 3. Effect of different weed control measures on *Orobanche* population and seed yield of mustard (2013-14)

Treatment	*Orobanche* panicles/m^2			Visual control (%) 120 DAS	Seed yield (t/ha)	Remarks
	60 DAS	90 DAS	120 DAS			
Neem cake 200 kg/ha in furrow and pendimethalin 0.5 kg/ha *fb* HW at 60 DAS	1.73(2)	1.73(2.0)	4.79(22)	0	1.48	
Neem cake 400 kg/ha in furrow *fb* HW at 60 DAS	2.65(6)	2.45(5)	4(15)	0	1.44	
Neem cake 200 kg/ha in furrow *fb* HW at 60 DAS	1.96(3)	2.0(3)	4.2(16)	0	1.45	
Pendimethalin 1.0 kg/ha *fb* HW at 60 DAS	2.52(5.3)	2.65(6)	4.97(24)	0	1.22	10% poor germination
Neem cake 400 kg/ha in furrow *fb* pendimethalin 0.5 kg/ha *fb* HW at 60 DAS	1.96(3)	2.76(6)	4.47(19)	0	1.38	
Glyphosate 25 and 50 g/ha at 30 and 55 DAS	1(0)	1(0)	1.73(2)	75	1.81	
Glyphosate 25 and 50 g/ha at 30 and 55 DAS with 1% $(NH_4)_2So_4$	1(0)	1(0)	1.41(1)	80	1.76	15% toxicity
Glyphosate 25 and 50 g/ha at 30 and 55 DAS(RP)	1(0)	1(0)	1.73(2)	75	1.78	
Glyphosate 25 g/ha at 30 DAS and 50 g/ha at 40 DAS	1(0)	1(0)	1.73(2)	75	1.80	5% crop suppression
Glyphosate 50 g/ha at 40 DAS	1(0)	1(0)	2.24(4)	60	1.70	10% crop suppression
HW at 30, 60 and 90 DAS	1.9(3)	3.51(11.3)	4.73(21)	0	1.58	
Trichoderma viride at 5 kg/ha before sowing	2.24(4)	3.42(10.7)	4.2(17)	0	1.60	
Weedy check	2.63(6)	3.51(11.3)	4.83(22)	-	1.40	
LSD (p=0.05)	0.20	0.18	0.22	-	0.035	

The results obtained earlier on efficacy of glyphosate were validated in large scale multi-locational trials conducted at different locations through farmers' participatory approach in Haryana State during the *Rabi* seasons of 2010-11 to 2016-17. A total of 758 demonstrations were conducted in mustard growing areas of Haryana state covering 1831 ha area and it was observed that overall 76.5% (range 40-95%) reduction in *Orobanche* weed infestation with 21.4% (range 13.9-38.7%) yield superiority was noticed with glyphosate treated plots (25 g/ha at 30 DAS followed by 50 g/ha at 55-60 DAS) when compared with the farmers' practice of one hoeing at 25-30 DAS (**Table 4**). This technology

Table 4. Comparative performance of glyphosate application *vis-à-vis* farmers' practice for *Orobanche* management and its subsequent effect on seed yield of mustard in large scale multi-locational trials

Year	No. of trials	Area covered (ha)	*Orobanche* Control (%)	Seed yield (t/ha)		Percent reduction in yield in farmer's practice
				Treated*	Farmer's practice*	
2010-11	12	5	82 (70-95)	1.72 (1.40-2.10)	1.49 (1.20-1.95)	15.5
2011-12	24	20	79 (65-90)	1.59 (1.20-2.20)	1.37 (0.90-1.80)	16.3
2012-13	86	156	72 (55-90)	1.75 (1.25-2.25)	1.54 (1.00-1.95)	13.9
2013-14	35	82	63 (40-90)	1.65 (1.25-2.40)	1.44 (1.10-2.10)	14.6
2014-15	119	486	80 (48-90)	1.85 (1.42-2.50)	1.50 (1.18-1.84)	23.4
2015-16	232	597	80 (79-87)	1.75 (1.13-2.22	1.26 (0.71-1.66)	38.7
2016-17	250	485	79 (75-84)	1.83 (1.48-2.28)	1.40 (1.25-1.55)	30.1
Mean	758	1831	76.5	1.73	1.43	21.4

*25 g/ha at 30 DAS and 50 g/ha at 55-60 DAS-2 sprays; **one hoeing at 25-30 DAS; figures in parenthesis indicate range of the treatment effect on *Orobanche* control and mustard seed yield.

has now spread to the most *Orobanche*-infested mustard-growing areas of Haryana and the farmers are fully convinced of the benefits of this low-cost technology.

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Integrated weed management in garlic with and without rice straw mulch

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ABSTRACT

A field experiment was conducted at AICRP on Weed Management Farm, BACA, AAU, Anand Gujarat during two consecutive *Rabi* season of 2016-17 and 2017-18 on loamy sand soil to study the effect of integrated weed management in garlic with and without rice straw mulch. The experiment was laid out in Split Plot design (SPT) with three replications. Rice straw mulch 5.0 t/ha applied after planting in conjunction with either application of oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP or tank mix application of pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE recorded significantly lower density and dry weight of weeds at harvest with higher weed control efficiency (91.9 and 85.9%, respectively), bulb weight (17.3 and 14.0 g/bulb, respectively), bulb yield of garlic (8.83 and 7.91 t/ha, respectively) along with the highest net return and B:C ratio.

INTRODUCTION

Garlic is one of the oldest cultivated spices and in production next to onion. It is cultivated commercially throughout the tropical and subtropical region of the world. The major garlic growing states are Gujarat, Uttar Pradesh and Madhya Pradesh, of these Madhya Pradesh ranks first in area (0.6 lakh ha) and production (2.7 lakh tonnes) with productivity of 4.5 t/ha (Anonymous 2014). Garlic is highly vulnerable to weed infestation due to its delay in emergence, slow initial growth habit, non-branching character, sparse foliage as well as fibrous root system (Rahman *et al*. 2012). Based on the study Kropff and Joije (1987) concluded that the density of weed species per unit area is not the only factors which cause the yield loss but also the time of the growth of weeds during the growing season would be more important. This leads to flourish the weeds and reduce the bulb yield to the tune of 61.77% under weedy plots as compared to hand weeded plots (Singh and Nandal 2002).

Looking to the yield losses, it is necessary to manage the weeds during initial growth stages either manually or by other practices. Mechanical methods required more labour and in present situation paucity of timely availability as well as high wages leads to choose alternative option. Under such circumstances herbicides considered as a boon to farmers in region where the limited availability of labours and high wages. Further, garlic is sensitive to moisture stress and high temperature responsible for drastic reduction in yield. Mulching with crop residues may held in conservation of soil moisture which reduce the moisture stress and also showed suppression effect on weeds. Umar *et al*. (2000) also reported that rice straw mulch has a capacity to suppress the growth of the weed effectively in garlic and onion besides maintain the soil moisture as well as congenial condition for better growth of the crop labours and high wages. The present investigation was planned to study the effect of integrated weed management practices with and without rice straw mulch on weeds, yield attributes and yield of garlic.

MATERIALS AND METHODS

A field experiment was conducted at AICRP-Weed Management Farm, B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat) during two consecutive *Rabi* season of the year 2016-17 and 2017-18 on loamy sand soil to study the effect of rice straw mulch and weed management practices on weeds, yield attributes and yield of garlic. The soil of experimental field was low in available nitrogen and medium in available phosphorus and high in potassium with pH 7.91. Sixteen treatment combination comprising two levels of rice straw mulch, *viz*. without mulch and with mulch 5 t/ha were allotted to main plot and eight weed management practices, *viz*. pendimethalin 500 g/ha PE *fb* HW at 60 DAP, pendimethalin 1000 g/ha PE, oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP, oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP, pendimethalin 500 g/ha + oxyfluorfen 120 g/ha PE (tank-mix), pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE (tank-mix), hand weeding at 30 and 60 DAP and weedy check were relegated in sub-plot under split-plot design with three replications. In treatment weeds were removed by manual uprooting without disturbing the mulch. The garlic cv. '*Gujarat*' *Garlic-4* was planted manually keeping the row distance of 15 x 10 cm at 600 kg seed/ha in second week of November during both the years of experimentation. Rice straw mulch was spread after planting of garlic as per treatment. Pre-emergence herbicides were applied before spreading of rice straw mulch while EPoE and PoE were applied after spreading of rice straw mulch as per treatments using knapsack sprayer fitted with flat fan nozzle. Immediately after sowing a light irrigation was given to the crop for uniform germination and next day the pre emergence herbicides were applied. The observations on number of weeds and dry weed biomass were taken from randomly selected four spots by using 0.25 m^2 iron quadrate from net plot area. Weed control efficiency (WCE) was calculated on the basis of standard formula as suggested by Maity and Mukherjee (2011). At the time of harvest, bulb yield was recorded from the net plot area and converted in to hectare. Data on various observations during the experiment period was statistically analysed as per the standard procedure developed by Cochran and Cox (1957).

RESULTS AND DISCUSSION

Effect on weeds

Based on the two years pooled data, the overall dominance of dicot and monocot weeds was 83.1 and 16.9%, respectively in the experimental field. Over all on pooled basis, the major weeds observed in the experimental field were *Eleusine indica* (8.9%), *Asphodelus tenuifolius* (3.0%), *Setaria gluaca* (0.92%) and *Digitaria sanguinalis* (0.92%) in monocot weeds category and *Chenopodium murale* (60.6%), *Chenopodium album* (15.5%) and *Melilotus indica* (5.2%) in dicot weed category.

Pooled data indicated that density of weeds recorded at 40 and 90 DAP and weed dry biomass at harvest was significantly influenced by mulching and weed management practices while dry weight of weeds was found significant only at harvest (**Table 1**). Significantly lower density (5.72 and 4.63/m^2 at 40 and 90 DAP, respectively) was observed under rice straw mulch 5.0 t/ha applied after planting over no mulch on pooled basis. Lower weed dry biomass of weeds was also observed in case of rice straw mulch 5.0 t/ha applied after planting. This result indicates the effectiveness of rice straw mulch on suppression effect on weeds over without mulch. Mulch controls the weeds by smothering seedlings, prevent day light which helps foster germination from reaching weed seeds and prevents airborne seeds from taking hold on the soil surface (Amoroso *et al.* 2009). At all the intervals maximum density and weed dry weight was recorded under without straw mulch treatment.

Table 1. Weed density and weed dry biomass as influenced by different weed management practices (pooled over 2 years)

Treatment	Weed density at 40 DAP (no./m^2)	Weed dry biomass at 40 DAP (g/m^2)	Weed density at 90 DAP (no./m^2)	Weed dry biomass at 90 DAP (g/m^2)	WCE (%) at 90 DAP	Weed dry biomass at harvest (g/m^2)	WCE (%) at harvest
Mulching (M)							
Without straw mulch	9.28(102)	6.53(53.8)	6.30(49.3)	13.4(280)	-	16.5(341)	-
Rice straw mulch 5.0 t/ha	5.72(45.1)	3.94(23.1)	4.63(28.0)	9.24(141)	-	12.8(227)	-
LSD (p=0.05)	0.270	NS	0.159	NS	-	0.596	-
Weed management practice (W)							
Pendimethalin 500 g/ha PE *fb* HW at 60 DAP	8.71(82.5)	7.17(57.5)	4.47(20.9)	6.38(46.3)	92.9	12.7(195)	78.9
Pendimethalin 1000 g/ha PE,	6.01(38.3)	5.07(29.8)	5.95(35.5)	18.5(420)	36.0	18.6(387)	58.1
Oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP	5.67(38.6)	4.39(24.8)	1.73(2.67)	2.44(7.05)	98.9	8.15(74.5)	91.9
Oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP	9.28(88.2)	4.31(18.6)	4.72(22.6)	5.43(29.3)	95.5	11.4(151)	83.6
Pendimethalin 500 g/ha + oxyfluorfen at 120 g/ha PE (tank-mix)	5.97(41.3)	4.25(22.2)	6.84(55.8)	14.8(309)	52.9	15.0(269)	70.9
Pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE (tank-mix)	4.27(18.8)	2.53(5.62)	5.86(36.8)	12.0(180)	72.6	10.9(130)	85.9
Hand weeding at 30 & 60 DAP	4.49(20.3)	2.57(5.93)	3.68(14.0)	5.82(35.1)	94.6	11.0(139)	84.9
Weedy check	15.6(258)	11.6(143)	10.5(121)	25.2(656)	-	29.4(923)	-
LSD (p=0.05)	3.25	3.11	4.50	9.07	-	5.88	-
Interaction M x W	Sig.	Sig.	NS	Sig.	-	Sig.	-

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

Among the weed management practices, significantly lower density and dry weight of weeds at 40 DAP was recorded under tank mix application of pendimethalin 500 g/ha EPoE + oxyfluorfen 120 g/ ha EPoE as compared to pendimethalin 500 g/ha PE *fb* HW at 60 DAP, oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP and weedy check. At 90 DAP, application of oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP recorded significantly lower density of weeds as compared to tank mix application of pendimethalin 500 g/ha + oxyfluorfen 120 g/ha PE and weedy check. Birgani and Sekhavat (2011) observed that application of oxyfluorfen effectively reduced more dry weight of weeds than other herbicides. The variation in density of weeds under different treatments might be due to effectiveness of herbicides and time of application. These findings are in accordance with the results of Shashidhar *et al*. (2013), they also reported that application of oxyfluorfen and pendimethalin provide effective control of weeds in garlic. At harvest, significantly lower dry weight of weeds was recorded under application of oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP but it was at par with tank mix application of pendimethalin 500 g/ha EPoE + oxyfluorfen 120 g/ha EPoE, twice hand weeding at 30 and 60 DAP, oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP and pendimethalin 500 g/ha PE *fb* HW at 60 DAP. The reduction in density of weed in herbicide treatments might be due to broad spectrum herbicidal effect on control of weeds which ultimately reflected in recording lower dry weight of weeds. These results are agreement with the findings of Sampat *et al*. (2014) and Mohite *et al*. (2015). Based on the two years pooled data, weedy check registered the highest density and dry weight of weeds at 40, 60 DAP and at harvest. The highest weed control efficiency of 91.9 per cent was recorded under application of oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP closely followed by tank mix application of pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE and twice hand weeding at 30 and 60 DAP. Higher weed control efficiency under said treatments might be due to equally effective in lowering total weed biomass as compared to other weed control treatments.

Pooled data on interaction effect presented in Table 3 indicated that dry weight of weeds at harvest was recorded significantly lower under rice straw mulch 5 t/ha along with application of oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP (M_1W_3) but it was at par with rice straw mulch 5 t/ha along with tank mix application of pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE (M_1W_6). The lower weed dry weight under said treatment might be due to suppression effect of mulch on weeds as well as control of weeds with herbicides which ultimately reduced the density of weeds and thereby weed dry weight. Significantly the highest dry weight of weeds was recorded in weedy check under rice straw mulch 5 t/ha and without mulch treatment.

Effect on crop

Plant stand was found to be non significant at 15 DAP while it was significant at harvest due to mulching treatment in pooled results (**Table 2**). Significantly higher plant stand (7.19 no./m^2) was observed under rice straw mulch 5 t/ha applied after

Table 2. Effect of mulching and weed management practices on growth, yield attributes, yield and economics of garlic (pooled over two years)

Treatment	Plant stand (no./m row length)		Plant height (cm)		Plant dry biomass (g/plant at 60 DAP	Bulb weight (g)	Bulb yield (t/ha)			Gross return ($x10^3$ `/ha)	Cost of cultivation ($x10^3$ `/ha)	Net return ($x10^3$ `/ha)	B:C ratio
	At 15 DAP	At harvest	At 60 DAP	At 90 DAP			2016-17	2017-18	Pooled				
Mulch (M)													
Without mulch	9.82	6.07	37.7	54.4	0.78	6.11	2.70	2.81	2.76	82.69	87.98	-5.30	0.92
With mulch (5.0 t/ha)	9.79	7.19	42.4	61.0	1.21	12.2	6.24	6.06	6.15	184.57	94.76	89.81	1.93
LSD (p=0.05)	NS	0.38	1.25	2.57	0.04	0.32	0.39	0.30	0.16	-	-	-	-
Weed management practice (W)													
Pendimethalin 500 g/ha PE *fb* HW at 60 DAP	9.82	7.07	44.2	57.9	1.04	10.5	4.59	4.50	4.55	136.50	92.94	43.56	1.44
Pendimethalin 1000 g/ha PE	9.77	6.42	41.5	61.5	1.12	7.20	2.94	3.23	3.09	92.55	88.42	4.13	1.02
Oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP	9.75	8.35	38.7	59.0	1.19	13.6	7.71	7.17	7.44	223.05	92.85	130.20	2.39
Oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP	9.85	7.42	40.0	54.8	0.94	9.30	4.75	4.51	4.63	138.90	92.85	46.05	1.49
Pendimethalin 500 g/ha PE + oxyfluorfen 120 g/ha PE (tank-mix)	9.82	6.23	41.5	61.2	1.10	9.36	4.30	4.31	4.31	129.30	88.86	40.44	1.42
Pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE (tank-mix)	9.88	7.67	38.6	59.2	1.09	10.4	5.57	5.51	5.54	166.35	88.86	77.49	1.84
Hand weeding at 30 and 60 DAP	9.83	7.88	38.2	56.0	1.09	11.3	5.81	6.04	5.92	177.75	100.23	77.52	1.76
Weedy check	9.72	2.00	37.7	52.0	0.39	1.90	0.10	0.21	0.15	4.65	85.99	-81.34	0.05
LSD (p=0.05)	NS	1.59	NS	NS	0.32	0.50	0.46	0.31	0.27	-	-	-	-
Interaction M x W	NS	NS	Sig.	NS	Sig.	Sig.	Sig.	Sig.	Sig.	-	-	-	-

planting as compared to without mulch in pooled results. Similarly, plant height measured at 60 and 90 DAP, plant dry biomass at 60 DAP, bulb weight and bulb yield was recorded significantly higher under rice straw mulch 5 t/ha applied after planting as compared to without mulch in pooled results. Higher yield attributes and yield indicated the positive effect of rice straw mulch on moisture retention, temperature regulation and weed suppression, which invariably become manifested in higher bulb yield of garlic. Increasing yield attributes of garlic due to application of straw mulch was also observed by Jamil *et al*. (2005). Higher bulb yield of garlic in response to mulching have been reported by Umar *et al.* (2000).

Among weed management practices, significantly the lowest plant stand was observed under weedy check at harvest while maximum plant stand was recorded under application of oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP in pooled results. The lower plant stand under weedy check treatment might be due to sever crop-weed competition suppress the growth of plant and restrict the photosynthesis. These results are in conformity with the results of Jamil *et al*. (2005). Further, plant height at both the intervals was found to be non significant due to different weed management practices. Significant variation was observed in plant dry biomass due to weed management practices at 60 DAP in pooled. Significantly higher plant dry biomass (1.19 g/plant) was recorded with rice straw mulch 5.0 t/ha as compared to weedy check. Garlic bulb weight was recorded significantly the highest under application of oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP. The intense competition of garlic plants with weeds resulted in a decrease in the weight of produced cloves of garlic. Significantly the highest bulb yield (7.44 t/ha) was obtained under application of oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP. The higher yield under application of oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP might be due to plant used the best from the resulted ecological niche under weed free environment resulted in enhanced availability of all the resources to the optimal level and it could transfer more photosynthetic materials to the reproductive organs and it could increase the bulb yield with producing more number of cloves/bulb with higher weight. Present findings are in close agreement with the findings of Makani and Shimi, (2009), Malik *et al.* (2017) and Siddhu *et al.* (2018). Interaction effect on pooled results indicated that significantly the highest bulb weight and bulb yield was recorded under rice straw mulch 5.0 t/ha along with application of oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP (**Table 4**). While the lowest bulb weight and bulb yield was observed in case of weedy check treatment combination in pooled.

Table 3. Interaction effect of mulching and weed management practices on weed dry biomass (g/m²) at harvest (pooled over two years)

Weed management practice / Rice straw Mulch	Pendimethalin 500 g/ha PE *fb* HW at 60 DAP	Pendimethalin 1000 g/ha PE	Oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP	Oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP	Pendimethalin 500 g/ha PE + oxyfluorfen 120 g/ha PE (TM)	Pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE (TM)	Hand weeding at 30 and 60 DAP	Weedy check
Without mulch	13.4	19.6	9.62	13.0	20.7	13.1	11.6	30.8
With mulch (5.0 t/ha)	12.0	17.5	6.68	9.77	9.23	8.59	10.4	28.1
LSD (p=0.05) 2.18								

Table 4. Interaction effect of mulching and weed management practices on bulb weight and bulb yield (pooled over two years)

Weed management practice / Rice straw mulch	Pendimethalin 500 g/ha PE *fb* HW at 60 DAP		Pendimethalin 1000 g/ha PE		Oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP		Oxyfluorfen 240 g/ha PoE *fb* HW at 60 DAP		Pendimethalin 500 g/ha PE + oxyfluorfen 120 g/ha PE (TM)		Pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE (TM)		Hand weeding at 30 and 60 DAP		Weedy check	
	bulb weight (g)	bulb yield (t/ha)	bulb weight (g)	bulb yield (t/ha)	bulb weight (g)	bulb yield (t/ha)	bulb weight (g)	bulb yield (t/ha)	bulb weight (g)	bulb yield (t/ha)	bulb weight (g)	bulb yield (t/ha)	bulb weight (g)	bulb yield (t/ha)	bulb weight (g)	bulb yield (t/ha)
Without mulch	6.29	2.31	3.83	1.11	9.89	6.04	8.05	3.81	4.65	1.08	6.70	3.18	8.13	4.42	1.35	0.10
With mulch (5.0 t/ha)	14.7	6.79	10.6	5.06	17.3	8.83	10.6	5.45	14.1	7.54	14.0	7.91	14.4	7.43	1.73	0.21
	bulb weight (g)	bulb yield (t/ha)														
LSD (p=0.05)	0.97	0.44														

Economics

Two years pooled data presented in **Table 2** further indicated that rice straw mulch 5.0 t/ha recorded higher gross return, net return and benefit cost ratio as compared to without mulch. Among weed management practices, application of oxyfluorfen 240 g/ha PE *fb* HW at 60 DAP recorded higher gross return, net return and benefit cost ratio which was closely followed by tank mix application of pendimethalin 500 g/ha + oxyfluorfen 120 g/ha EPoE and twice hand weeding carried out at 30 and 60 DAP.

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Monthly nutrient uptake by weeds in different land use systems at two locations of Punjab, India

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ABSTRACT

In present study, biomass production and nutrient status (NPK) of weeds in three land use systems (canal bunds, fallow land and in cultivated land) at two locations (Ludhiana and Sangrur) of Punjab was analyzed throughout year (Jan-Dec 2017) at monthly interval. In case of land use systems fallow land (Sangrur) was recorded to have maximum total biomass (5.73 t/ha), nitrogen (96.9 kg/ha), phosphorus (21.5 kg/ha) and potassium (85.9 kg/ha). With respect to months, total maximum weed biomass production (7.40 t/ha), nitrogen (147.8 kg/ha), phosphorus (27.8 kg/ha) and potassium (125.8 kg/ha) was recorded in July. Thus from present data it is revealed that weeds which grow lavishly in fallow lands of Punjab possess high nutrient value and dry matter production of weeds in this land use system increased with heavy rainfall.

INTRODUCTION

Weeds are unwanted plants that grow out of place. These can be seen growing lavishly in fallow lands, rock cervices, city wastelands, roadsides, railway cracks and orchards. Weeds have evolved mechanisms to cope with stresses and exploit opportunities of disturbances (Mohler 2001). Increasing pressure to enhance output from limited land has increased use of herbicides, synthetic fertilizers and insecticides. These in turn have adversely affected quality of soil and underground water. So to overcome these problems of weeds interest of people in organic farming is increasing day by day. Organic farming is a production system which avoids use of herbicides, fertilizers and pesticides and relies merely on recycling of nutrients produced on the farm. Farmyard manure (FYM) and compost are main sources of manuring in organic farming and these are becoming scare and costly due to reduction in cattle population and increase in mechanization. Weed species could be used in enriching the compost as nutrient content of weeds is generally high. The present study was an attempt to estimate nutrient content in weed species and to identify the weed species which could possibly be used in-situ or mixed with compost as a resource of nutrients.

Parthenium hysterophorus, Cassia serecia, Chromolaena sp. and *Portulaca oleracea* which grow in abundance in wastelands were effectively used in cultivation of hybrid sorghum by Channappagovdar *et al* (2007). Hybrid maize was cultivated with composts of these four weeds prepared at two stages (before and after flowering) along with organic manures *i.e.* farmyard manure, poultry and cow dung waste. Nitrogen content was highest in compost of *P.hysterophorus* (2.95%) followed by *Chromolena* sp (2.32) at pre-flowering stage. Poultry compost had highest phosphorus (1.6%) and potassium (1.42%) whereas *P.hysterophorus* contained 0.82% phosphorus and 1.3% potassium.

MATERIALS AND METHODS

Study site

The present study was carriedin2017 (January - December) in three land use systems *i.e.* fallow land, canal bunds and cultivated land of two locations in Punjab, *viz.* Ludhiana (30.54° N and 75.48° E) and Sangrur (30.25° N and 75.84° E) districts. The climate of both sites was subtropical humid with very hot summers and cold winters.

Monthly meteorological data of Ludhiana and Sangrur for period January - December 2017, are given in figure 1 and figure 2, respectively.

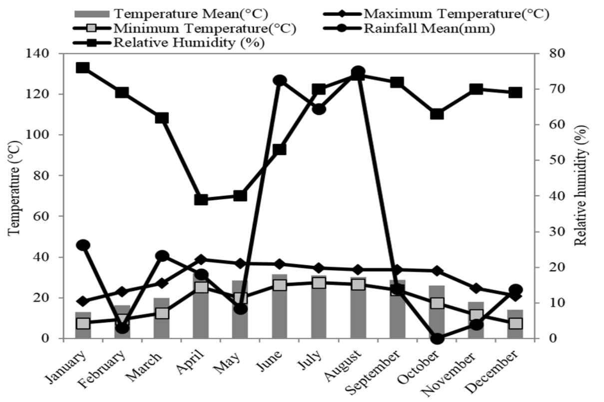

Figure 1. Monthly meteorological data of Ludhiana for period January - December 2017

Source: School of Climate Change and Agrometerology, PAU, Ludhiana

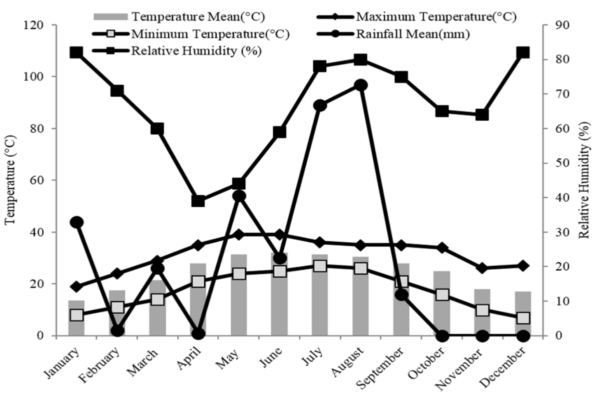

Figure 2. Monthly meteorological data of Sangrur for the period January - December 2017

Source: Krishi Vigyan Kendra, Kheri, Sangrur

Methods

In each land use system of both locations two fixed quadrats (1.0 x 1.0 m) were laid down in three replications. The plants were uprooted along with roots from these quadrats at an interval of 30 days and weed species names were recorded. The uprooted weeds were dried first in the field and then in oven. The dried samples were together ground and then analyzed for macro nutrients *i.e.* Nitrogen, phosphorus and potassium.

Estimation of nutrients

Nitrogen, phosphorus and potassium were estimated by following standard procedures.

a. Nitrogen: Wesertmann (1990)

b. Phosphorus: Vanado molybdo phosphoric acid method by Jackson 1987

c. Potassium: Flame photometric method by Chapman and Pratta 1961

$$\text{Nutrientuptake (kg/ha)} = \frac{\text{Nutrient concentration (\%) Î dry matter (kg/ha)}}{100}$$

Statistical analysis

To test the significance of treatments analysis of variance (ANOVA) followed by least significant difference (LSD) test at p= 0.05 level was carried out.Experiment data was analyzed as per standard statistical procedure for factorial randomized block design as prescribed by Cochran and Cox (1967) and adapted by Cheema and Singh (1991) in statistical package CPCS1, software developed by Department of Mathematics and Statistics, PAU, Ludhiana.

RESULTS AND DISCUSSION

The weed species uprooted from quadrats of each location showed variation with respect to locations and land use systems. All the weed species recorded from studied sites were alphabetically arranged and presented in **Table 1**.

Weed biomass production was found to vary significantly during different months as well as locations and land use systems (**Table 2**). Maximum biomass production was recorded in fallow land at both locations in month of July with values of 1.33 t/ha (Ludhiana) and 3.74 t/ha (Sangrur) followed by biomass production in September. Similarly, canal bunds of Sangrur showed maximum production in July (1.22 t/ha) however in Ludhiana canal bunds it was reported in September (0.65 t/ha). The cultivated land of both locations showed maximum biomass production in September *i.e.* 412.0 kg/ha (Sangrur) and 368.3 kg/ha (Ludhiana).

It was concluded that both in Ludhiana and Sangrur maximum mean rainfall was during June-September which effects the growth of weeds positively in all land use systems (**Figure 1**). Moreover, during the cold season *i.e.* in January minimum weed biomass was recorded in almost all land use systems.

Nitrogen

Differences in nitrogen uptake (**Table 3**) were statistically significant for months, location and land uses systems and their interactions. Plant species in fallow lands of both locations *i.e.* Ludhiana and Sangrur showed increase in nitrogen uptake from January to July after which it declined at both land use systems and locations.

In case of canal bunds, maximum nitrogen uptake by weed species in Ludhiana was recorded in September (15.2 kg/ha) whereas in Sangrur it was recorded in July (23.5 kg/ha).

In Cultivated land of both locations, maximum nitrogen uptake by plant species was recorded in March with values 5.4 kg/ha in Sangrur and 7.6 kg/ha in Ludhiana.

Table 1. Plant species recorded in different land use systems

Land use systems Months	Fallow land (Ludhiana)	Fallow land (Sangrur)	Canal bunds (Ludhiana)	Canal bunds (Sangrur)	Cultivated land (Ludhiana)	Cultivated land (Sangrur)
January	*Cassia occidentalis*	*Achyranthes aspera*	*Cannabis sativa*	*Abutilon indicum*	*Anagalis arvensis*	*Anagalis arvensis*
	Chenopodium album	*Cannabis sativa*	*Cassia occidentalis*	*Cannabis sativa*	*Sisymbrium irio*	*Cynodon dactylon*
	Malva parviflora	*Cassia occidentalis*	*Chenopodium album*	*Urena lobata*	*Spergula arvensis*	*Stellaria media*
	Parthenium hysterophorus	*Dicliptera brachiata*	*Cenchrus biflorus*	-	*Stellaria media*	-
	Sisymbrium irio	*Urena lobata*	*Ricinus communis*	-	-	-
March	*Cassia occidentalis*	*Cannabis sativa*	*Cannabis sativa*	*Abutilon indicum*	*Gnaphalium purpureum*	*Foeniculum vulgare*
	Cannabis sativa	*Cassia occidentalis*	*Cassia occidentalis*	*Cannabissativa*	*Malvaparviflra*	*Cynodon dactylon*
	Parthenium hysterophorus	*Sisymbrium irio*	*Chenopodium album*	*Chenopodium album*	*Sisymbrium irio*	*Malva parviflora*
	Sida acuta	*Spergula arvensis*	*Malva parviflora*	*Urena lobata*	*Spergula arvensis*	-
	Sisymbrium irio	*Urena lobata*	-	-	-	-
May	*Cassia occidentalis*	*Achyranthes aspera*	*Achyranthes aspera*	*Cannabis sativa*	*Amaranthus viridis*	*Foeniculum vulgare*
	Cannabis sativa	*Cannabis sativa*	*Cannabis sativa*	*Chenopodium album*	*Bidens pilosa*	*Cynodon dactylon*
	Parthenium hysterophorus	*Cassia occidentalis*	*Cassia occidentalis*	*Abutilon indicum*	*Eragrostis tenella*	-
	Sida acuta	*Parthenium hysterophorus*	*Parthenium hysterophorus*	-	-	-
	Tephrose pupurea	*Urena lobata*	-	-	-	-
July	*Artemisia scoparia*	*Boerhaavia diffusa*	*Cannabis sativa*	*Boerhaavia diffusa*	*Eragrostis tenella*	*Digitaria sanguinalis*
	Cassia occidentalis	*Chenopodium album*	*Cassia occidentalis*	*Cannabis sativa*	*Bidens pilosa*	*Trianthema portulacastrum*
	Cannabis sativa	*Parthenium hysterophorus*	*Parthenium hysterophorus*	*Chenopodium album*	*Dactyloctenium aegyptium*	-
	Chenopodium album	*Sida acuta*	-	-	-	-
	Parthenium hysterophorus	*Tribulus terrestris*	-	-	-	-
September	*Artemisia scoparia*	*Cannabis sativa*	*Achyranthes aspera*	*Achyranthes aspera*	*Commelina benghalensis*	*Cannabis sativa*
	Cassia occidentalis	*Cassia occidentalis*	*Cassia occidentalis*	*Cannabis sativa*	*Digitaria sanguinalis*	*Rumex dentatus*
	Cannabis sativa	*Parthenium hysterophorus*	*Parthenium hysterophorus*	*Chenopodium album*	*Bidens pilosa*	-
	Chenopodium album	*Sida acuta*	-	-	-	-
	Parthenium hysterophorus	*Tribulus terrestris*	-	-	-	-
November	*Cassia occidentalis*	*Cannabis sativa*	*Chenopodium album*	*Chenopodium album*	*Amaranthus viridis*	*Chenopodium album*
	Cannabis sativa	*Cassia occidentalis*	*Sida acuta*	*Sida acuta*	*Cassia occidentalis*	*Rumex dentatus*
	Dicliptera brachiate	*Parthenium hysterophorus*	*Sisymbrium irio*	*Sisymbrium irio*	*Chenopodium album*	-
	Parthenium hysterophorus	*Sida acuta*	*Urena lobata*	*Urena lobata*	*Digitaria sanguinalis*	-
	Sida acuta	*Tephrosia purpurea*	-	-	-	-

Phosphorus

Phosphorus uptake (**Table 4**) for locations, months and land use systems and their interactions differed significantly.

The maximum uptake value for plants of fallow land of Ludhiana and fallow land of Sangrur was 3.8 kg/ha and 17.7 kg/ha respectively which was recorded in July.

Table 2. Monthly biomass production (kg/ha) in different land use systems of two locations

Land use / Locations / Months	Fallow land		Canal bunds		Cultivated land	
	Ludhiana	Sangrur	Ludhiana	Sangrur	Ludhiana	Sangrur
January	164.2	268.0	183.3	93.2	212.2	194.8
March	220.5	226.5	106.2	33.3	266.8	230.3
May	284.3	233.0	177.3	178.7	277.7	214.5
July	1331.3	3744.3	486.2	1219.3	360.7	256.5
September	484.5	650.2	650.0	970.7	412.0	368.3
November	264.7	606.3	274.2	334.5	232.0	184.8
Mean	458.3	954.7	312.9	471.6	293.6	241.5
Total	2748.8	5733.0	1885.3	3009.5	1763.1	1456.2

LSD (p= 0.05) LSD (month): 27.8, LSD (location):16.0, LSD (land use): 19.6
LSD (month*location): 39.3, LSD (month*land use): 48.1; LSD (landuse*location): 27.8, LSD (month*location*land use): 68.0

Table 3. Monthly nitrogen uptake (kg/ha) by weeds in different land use systems at two locations

Land use / Locations / Months	Fallow land		Canal bunds		Cultivated land	
	Ludhiana	Sangrur	Ludhiana	Sangrur	Ludhiana	Sangrur
January	4.0	3.1	4.6	1.1	6.7	4.4
March	5.9	2.5	2.7	0.6	7.7	5.4
May	6.1	5.7	4.8	2.5	4.6	2.8
July	29.6	66.1	8.4	23.5	7.6	4.5
September	11.5	8.3	15.2	17.4	5.7	5.2
November	4.5	11.2	5.2	11.1	2.5	5.3
Total	61.7	96.9	40.9	56.3	34.8	27.7
Mean	10.3	16.2	6.8	9.4	5.8	4.6

LSD (p= 0.05) LSD (month): 8.4, LSD (location): 4.9, LSD (land use): 5.9
LSD (month*location): 0.6, LSD (month*land use): 11.9, LSD (month*location*land use): 20.7

Table 4. Monthly phosphorus uptake (kg/ha) by weedsn in different land use system at two locations

Land use / Locations / Months	Fallow land		Canal bunds		Cultivated land	
	Ludhiana	Sangrur	Ludhiana	Sangrur	Ludhiana	Sangrur
January	0.5	0.3	0.4	0.2	0.7	0.46
March	0.6	0.7	0.3	0.1	1.2	0.65
May	1.2	0.4	0.3	0.4	0.3	0.35
July	3.9	17.7	1.1	3.7	0.5	0.92
September	0.8	1.5	1.1	1.5	1.4	0.80
November	1.1	0.9	0.9	1.0	0.7	0.36
Total	8.1	21.6	4.1	6.9	4.9	3.5
Mean	1.4	3.6	0.7	1.2	0.8	0.6

LSD (p= 0.05) LSD(month): 0.39, LSD (location): 0.5, LSD (land use): 0.62
LSD (month*location): 0.12, LSD (month*land use): 0.76, LSD (month*location*land use): 0.25

Canal bunds plants also showed maximum values in July which was 3.6 kg/ha and 1.1 kg/ha for Sangrur and Ludhiana respectively.

For cultivated land plants nutrient uptake, in Ludhiana maximum uptake recorded was 1.4 kg/ha in September however, in Sangrur maximum value recorded was 0.9 kg/ha in July.

Potassium

Differences inpotassium uptake (**Table 5**) were also highly significant for locations, months and land use systems and their interaction.

Maximum potassium uptake by plants in fallow land of both locations was recorded in July with values 32.6 kg/ha (Ludhiana) and 52.3 kg/ha (Sangrur).

In case of canal bunds, for Sangrur maximum uptake of 24.9 kg/ha by weed species was recorded in July whereas in Ludhiana maximum uptake *i.e.* 11.9 kg/ha was recorded in September.

For cultivated land Sangrur maximum potassium uptake *i.e.* 6.3 kg/ha by plants was recorded for January whereas in Ludhiana maximum production *i.e.* 6.1 kg/ha was recorded in September.

Table 5. Monthly potassium uptake (kg/ha) by weeds in different land use system at two locations

Land use / Locations / Months	Fallow land		Canal bunds		Cultivated land	
	Ludhiana	Sangrur	Ludhiana	Sangrur	Ludhiana	Sangrur
January	6.7	4.6	4.7	1.43	4.7	6.3
March	5.5	5.8	2.3	0.6	5.1	4.9
May	10.2	7.8	4.6	3.1	3.1	2.7
July	32.6	52.3	10.7	24.3	3.5	2.7
September	7.7	6.6	11.9	11.4	6.1	6.2
November	4.8	9.1	3.8	8.6	3.9	2.4
Total	67.6	85.8	37.9	49.2	26.4	25.1
Mean	11.3	14.4	6.3	8.2	4.4	4.2

LSD (p= 0.05) LSD (month): 0.1, LSD (location): 0.7, LSD (land use): 0.9
LSD (month*location): 0.2, LSD (month*land use): 2.0, LSD (month*location*land use): 2.9

In present study, the biomass production and nutrients uptake (NPK) was recorded to be maximum in July / September and among land use systems maximum content was recorded for fallow land (Sangrur). Nutrient uptake is a function of dry weight and so nutrient uptake increased with increase in dry biomass. The rainfall recorded was also maximum in July which favored growth of highly dense weeds population and eventually increased the biomass production in turn nutrient uptake also increased. Besides environmental conditions, it was also recorded that in these months majority of plants were in flowering stage. Thus, at flowering stage nutrient uptake by plants is generally high.

Similarly dry weight and NPK content in herbaceous weeds in fields of *Nigella sativa* grown in arid areas of Iran for two years (2011 to 2012) was recorded by Seyyedi *et al.* (2016). It was concluded that dry weight and NPK of *N. sativa* weeds increased with increase in weed infestation. In this study it was also reported that with increase in weed infestation NPK content is 1.8-2 times higher in weeds compared to *N. sativa* crop.

Mahanta *et al.* (2009) recorded NPK content of many important terrestrial weeds, *viz. Achyranthes aspera*: 1.90, 0.75 and 2.50%, in *Amaranthus viridis*: 3.16, 0.06 and 4.51%, in *Chenopodium album*: 2.59, 0.37 and 4.34%, in *Cynodon dactylon* 1.72, 0.24 and 1.75% and in *Cyperus rotundus*: 2.17, 0.26 and 2.73%. It was concluded in this study that due to such a high per cent of nutrient composition, these herbaceous terrestrial weeds can be used in preparation of green manures, which are best alternative of chemical fertilizers.

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Heavy metal removal by greater club rush (*Scirpus grossus*) *vs* water hyacinth in a wetland ecosystem

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ABSTRACT

Removal of heavy metals by the invasive alien weed greater club rush (*Scirpus grossus* L. f) in a wetland ecosystem was estimated and compared with water hyacinth (*Eichhornia crassipes*) to assess its efficiency as a phytoremediator. The study was conducted during October-December 2016 by collecting soil and plant samples from an industrially polluted locality in Thiruvananthapuram district, Kerala. Results showed that in both the species, the metal concentration was more in the root system than in the shoot portion. Total metal uptake pattern in greater club rush was Cu>Cr>Zn>Ni>Pb>Co>Cd>As, while in water hyacinth it was Cu>Zn>Ni>Cr>Pb>Co>As>Cd. It was concluded that greater club rush with its huge biomass production (>30 t/ha), could remove many of the heavy metals from contaminated soils more efficiently than water hyacinth. Biological concentration factor (BCF), translocation factor (TF) and biological accumulation coefficient (BAC) calculated for assessment of heavy metal mobility also suggested that greater club rush has the potential to be utilised for phytoremediation of contaminated soils.

INTRODUCTION

Many of the aquatic plants are capable of assimilating large quantities of trace elements and heavy metals which make them efficient phytoremediators and better competitors under adverse conditions. Several of these metals are essential, but at the same time also toxic at higher concentrations, because they cause oxidative stress by the formation of free radicals (Khayatzadeh and Abbasi 2010). Though phytoremediation is an effective and cheaper strategy for removing contaminants from soil, the prospective of this technology depends on the capability of plants to extract large concentrations of heavy metals into their roots, translocate them to surface biomass, and produce a large quantity of plant biomass (Ghosh and Singh 2005).

Greater club rush (*Scirpus grossus* L. F), is a very large wetland herb, which has attained the status of a difficult invasive species in vast tracts of wetlands in Kerala. The emergent hydrophyte is a native of South East-Asia and is found naturalized throughout India, Malaysia, and Tropical Australia (Naskar 1990). Jinadasa *et al.* (2006) examined the ability of greater club rush planted in a constructed wetland to treat domestic waste water and reported that the herb has great potential to remove pollutants in contaminated soils.

There are several earlier reports indicating the effective removal of contaminants by water hyacinth (*Eichhornia crassipes*), especially in wetlands, owing to its fast growth rate and heavy uptake of contaminants (Rai 2009). It has also been effectively used as an indicator of heavy metal pollution (Pleiffer *et al.* 1986). It is considered as a phytoremediator even with low levels of Zn, Cr, Cu, Cd, Pb, Ag and Ni (Odjegba and Fasidi 2007).

Hence, the present study was undertaken to estimate the potential of greater club rush for heavy metal removal in comparison with water hyacinth growing in the same locality. Transfer and accumulation of heavy metals from soil to roots and shoots were also estimated by working out biological concentration factor (BCF), translocation factor (TF) and bioaccumulation coefficient (BAC), to assess the potential of the hydrophyte as as phytoremediator.

MATERIALS AND METHODS

Study area

The study was conducted during October-December 2016, by collecting soil and plant samples from an undisturbed-wetland located at Thiruvananthapuram district, Kerala (8°26'39.88" N latitude and 76°59'12.13" E longitude), which was heavily infested with both greater club rush and water hyacinth. The selected field was lying close to an industrial area wherein almost all sorts of waste, including sewage water, electronic wastes and human wastes were being dumped and hence was hypothesized to be contaminated with heavy metals.

Sampling and analytical procedures

Sample preparation and basic chemical analysis of soil were conducted according to routine analytical methods. Approximately one kg each of soil sample was collected randomly from five different points upto 15 cm depth, separately, from greater club rush and water hyacinth invaded spots. Soil samples were air dried at room temperature for two weeks, crushed and pulverized to pass through 2 mm sieve and three composite samples were drawn after homogenous mixing. Soil organic matter was determined by Walkley and Black method, pH was determined by pH meter and EC measured using conductivity meter. The available arsenic (As) copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), cobalt (Co), nickel (Ni) and chromium (Cr) were determined by the Inductively Coupled Plasma Mass Spectrophotometry (ICPMS - Thermoscientific, Model iCAP Qc) method.

Plant samples were also collected from the same sites from where the soil was collected. After thorough washing, samples were dried for two weeks. Then the below ground (root) and aerial (shoot) portions were separated and oven dried at 65° C till they attained constant weights. Dried samples were ground to a fine powder and three samples each of 0.1 g were used for heavy metal analysis by the Inductively Coupled Plasma Mass Spectrophotometry (ICPMS) method

The biomass production potential of greater club rush and water hyacinth was determined by collecting samples using quadrat method, wherein the quadrats (1 m^2) were placed randomly in ten sites for each of the plant species. The collected samples were washed, dried and the dry weights were determined and expressed as t/ha.

As total heavy metal concentration of soils is poor indicator of metal availability for plant uptake, the concentration, transfer and accumulation of metals from soil to roots and shoots was evaluated in terms of Biological Concentration Factor (BCF), Translocation Factor (TF) and Bioaccumulation Coefficient (BAC) using the following equations as suggested by Tukura *et al.* (2012).

BCF = Heavy metal content in root/ Heavy metal content in soil

TF = Heavy metal content in shoot/ Heavy metal content in root

BAC = Heavy metal content in shoot/ Heavy metal content in soil

RESULTS AND DISCUSSION

The average value of the chemical properties of the soil samples collected from the study area are presented in **Table 1**. The soil was strongly acidic (4.81) and non-saline with an EC value of 0.28 dS/m. The organic carbon content of the soil was 3.22% which rates the soil to be highly organic in nature with organic matter content of 5.53%.

Table 1. Chemical properties of the wetland soil

Parameter	Composition	Rating
pH	4.81	Strongly acidic
EC (dS/m)	0.28	Non saline
Organic carbon (%)	3.22	High
Organic matter (%)	5.53	High

Heavy metal composition of the soil

In spite of the presence of industrial and other wastes dumped in, the available heavy metal status of the soil (**Table 2**) was found to be well within the safe limits as per the regulatory standards for agricultural soils (He *et al.* 2015). The maximum content was recorded for Zn (13.42 ppm), followed by Cu (4.57 ppm), Pb (4.17 ppm), Ni (0.75 ppm), Cobalt (0.49) and Cr (0.3) while As and Cd were found below detectable limit (BDL). Such safe limits were probably because of the high organic matter status of the selected site which is reported to decrease heavy

Table 2. Heavy metal composition of the soil with regulatory standards for heavy metal contamination of soils

Heavy metal	Composition (ppm)	Max. permissible limit (ppm)#
Arsenic (As)	BDL	20
Copper (Cu)	4.57	100
Zinc (Zn)	13.42	300
Lead (Pb)	4.17	100
Cadmium (Cd)	BDL	3
Cobalt (Co)	0.49	50
Nickel (Ni)	0.75	72
Chromium	0.3	11

#Regulatory Standards for Agricultural Soils in USA (He *et al.* 2015) metal availability through immobilization (Yi *et al.* 2007). Blaylock and Huang (2000) suggested that for the heavy metals to be available in plant absorbable form, they should be in the soluble form or should be easily solubilised by root extracts. The removal of heavy metals by the invasive weeds as discussed later in this paper must also have contributed to the cleaning up of the soil.

Heavy metal accumulation in greater club rush and water hyacinth

The data on the concentration of heavy metals in the plant tissue (**Table 3**) indicated that both greater club rush and water hyacinth accumulated more of the metals in their root system than the shoots. Among the heavy metals, chromium, copper, zinc and cadmium were higher in greater club rush while nickel, cobalt, lead and arsenic were more in water hyacinth. The order of their concentration in greater club rush and water hyacinth were Cr>Cu>Zn>Ni>Pb>Co>As>Cd and Ni>Cr>Cu>Zn>Pb>Co>As>Cd respectively. It was found that both the species recorded the presence of As and Cd in their tissues, even though the soil status was below detectable limit (BDL). Evidently, plant absorption of heavy metals was not directly proportional to their concentration in the soil as many other factors like pH, temperature, plant species, size, its root system etc. influenced the uptake (Yammamoto and Kozlowski 1987). According to Ghosh and Singh (2005), high metal accumulation by plants may be attributed to well developed detoxification mechanism based on sequestration of the metal ions in vacuoles by binding them on appropriate ligands such as organic acids, proteins and peptides in the presence of enzymes and metal exclusion strategies of the plant species.

Table 3. Heavy metal composition of greater club rush and water hyacinth (ppm)

Heavy metals	Greater club rush			Water hyacinth		
	Shoot	Root	Average	Shoot	Root	Average
Arsenic (As)	0.18	1.35	0.77	0.20	2.78	1.49
Copper (Cu)	18.18	26.97	22.58	19.10	19.09	19.05
Zinc (Zn)	6.40	35.38	20.89	15.82	20.21	18.01
Lead (Pb)	1.83	6.95	4.39	11.84	5.33	8.59
Cadmium (Cd)	0.04	0.10	0.07	0.04	0.09	0.06
Cobalt (Co)	0.74	2.57	1.66	1.18	13.58	7.34
Nickel (Ni)	4.95	9.53	7.24	14.69	37.46	26.05
Chromium (Cr)	17.29	79.5	48.40	12.36	29.02	20.68

Uptake of heavy metals

Total metal uptake pattern in greater club rush was in order of Cu>Cr> Zn>Ni>Pb>Co>As>Cd while in water hyacinth it was Cu>Zn>Ni>Cr >Pb>Co>As>Cd (**Table 4**). It is well established that the uptake of an element by a plant primarily depends on the plant species, its inherent controls, and the soil quality (Chunilall *et al.* 2005).

Table 4. Uptake of heavy metals by greater club rush and water hyacinth

Heavy metals	Greater club rush (g/ha)	Water hyacinth (g/ha)
Arsenic (As)	55.31	0.23
Copper (Cu)	5586.71	21.39
Zinc (Zn)	1966.72	17.71
Lead (Pb)	562.36	13.26
Cadmium (Cd)	12.23	0.04
Cobalt (Co)	227.40	1.32
Nickel (Ni)	1521.14	16.45
Chromium (Cr)	5313.22	13.84
Total Biomass (t/ha) Production production(t/ha)	30	1.12

High biomass production is one of the important strategy for considering a plant for phyto extraction. The estimated biomass production of greater club rush was > 30 t/ha while that of water hyacinth was only 1.12 t/ha. Because of this huge difference in plant dry weight, the uptake of all the heavy metals by greater club rush was found much higher than that of water hyacinth, irrespective of their order of concentration in each of the species.

The concentration, transfer and accumulation of metals from soil to roots and shoots evaluated in terms of biological concentration factor (BCF), translocation factor (TF) and bioaccumulation coefficient (BAC) are presented in **Table 5**.

Table 5. Heavy metal accumulation and mobility

Heavy metals	Greater club rush			Water hyacinth		
	BAC	BCF	TF	BAC	BCF	TF
Arsenic (As)	-	-	0.13	-	-	0.04
Copper (Cu)	3.98	5.90	0.67	4.18	4.18	1.00
Zinc (Zn)	0.48	2.64	0.18	1.18	1.50	0.78
Lead (Pb)	0.44	1.67	0.26	2.84	1.28	2.22
Cadmium (Cd)	-	-	0.40	-	-	0.44
Cobalt (Co)	1.51	5.24	0.29	2.41	27.71	0.09
Nickel (Ni)	6.60	12.71	0.52	19.59	49.95	0.39
Chromium (Cr)	75.18	345.66	0.22	53.73	126.18	0.43

The BAC and BCF values for arsenic and cadmium could not be calculated as their presence in the soil was found below detectable limits (BDL). Accumulation factors give an idea about the bioavailability of the metals and the part of the plant where they accumulate (Tukura *et al.* 2012). In the present study, the BCF values were >1 and the TF were <1 for all the heavy metals in greater club rush. The BAC factor was also >1 for copper, cobalt and nickel; however, value for chromium was as high as 75.18. In water hyacinth, both BAC and BCF were >1 for all the metals and the TF value was<1 for all except copper and lead. Riffat *et al.* (2010) have observed that trace metal tolerant species with high BCF and low TF can be used for phytostabilization of contaminated soil. The high BAC and BCF values indicated that greater club rush is able to extract many of the heavy metals from soils and its efficiency was even better than that of water hyacinth. From the low TF values it was evident that these metals were mostly restricted in the root system, which in turn suggests the suitability of the aquatic herb both for phytextraction and phytostabilisation in contaminated soils.

Results of the study corroborate with the observations made by Ghosh and Singh (2005) that, as a 'blessing in disguise', in most of the contaminated sites, hardy large and tolerant species exist, to confine the contaminants from being introduced into the food web.

Considering the heavy metal accumulation and potential for huge biomass production greater club rush is suggested to be utilised as a phytoextractor for cleaning up soils contaminated with heavy metals especially Cr, Ni, Cu and Co. The BAC, BCF and TF values suggest the potential for phytostabilisation of Zn and Pb. The potential of such invasive species have to be explored so that contamination, especially in fragile ecosystems like wetlands can be restricted through eco-friendly techniques.

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Development of non-powered self-propelling vertical axis inter row rotary weeder

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ABSTRACT

Maize is the third most important cereal crop in India and is most susceptible to weed management practices. Weeding is one of the costliest and laborious operations in crop cultivation. Most of the existing weeders are of horizontal type and very less work done on vertical axis rotary weeders and energy aspects of the weeding units. A study was under taken to develop non-powered self-propelling vertical axis rotary weeder to eliminate the external powering unit, which provides the energy to cut the weeds and soil. The developed weeder was tested in maize crop at 2 and 4 cm of operational depth and 15 and 30 DAS of crop growth stages. The developed weeder performed very well at all the crop growth stages and obtained a weeding efficiency of 65 to 70% with 1.98 to 5.88% of plant damage. The highest cob yield of 12.9 t/ha was recorded weeding at 15 DAS followed by 30 DAS. However a care must be taken and a safety zone *i.e.* a gap of 7-10 cm between machine edges to the tip of plant leaves should be maintained to avoid the plant damage. At operational depth of 2 cm the draft force required to pull the weeding unit was 6.3 kgf and obtained field capacity was 0.08 ha/h, which was higher when weeder was operated at 4 cm of operational depth.

INTRODUCTION

The advanced agricultural practices such as precised application of agricultural inputs, timeliness of operation, proper selection of cropping systems *etc*. are need of the hour to enhance higher crop yields. Further, the man power involved, man-machine relationship, human drudgery and energy aspects in crop cultivation are other such parameters responsible to achieve energy efficient crop cultivation (Chethan and Krishnan 2017, Chethan *et al.* 2018a and b). Maize is the third most important cereal crop in India and is most susceptible to weed management practices The maize crop was heavy doses of fertilizers during its growth period to enhance the crop growth. This heavy doses was lead severe infestation of the weeds (Naidu and Murthy 2014, Mynavathi *et al.* 2015), thus crop yield was reduced drastically. Weeds malign the crop yield by absorption of nutrients and resources mainly supplied for optimum growth of crops (Slaughter *et al.* 2008). Weed management is a strategy that makes a desired plant population successful in a crop field by utilizing knowledge of the ecology of the weeds (Ghersa *et al.* 2000). But, weeding is one of the costliest and laborious operations in crop cultivation and needs effective and timely management of weeds. There are several existing methods of controlling weeds such as manual, chemical, biological or mechanical. The earliest and smoothest method of all is the manual weed control, where farmers used their hands to uproot weeds, which is then advanced to hand tools such as khurpi, hand-hoe etc. (Tewari *et al.* 1993). Herbicides are one of the crucial factors in a worldwide increase in cereal production. Clearly the farmer using herbicides in maize production is saving money but due to demand of chemical free food, there is a need of efficient weeding technique to cut and mix the weeds in maize field.

The weed control is a frequent process and so the labor requirement in manual weeding method is very expensive, time consuming and difficult (Weide *et al.* 2008). The introduction of chemical weed control methods has relieved the weeding operation from these undesirable factors (Tewari *et al.* 2014, Chandel *et al.* 2018). However, due to herbicide-resistant weeds, environmental impact of herbicides and increasing demand for non-toxic foods, investigations of alternative methods of weed control has gained popularity.

Mechanical inter-row weeders such as inter-row cultivators, rotary cultivators and basket weeders are available in the market (Cloutier *et al.* 2007, Tewari and Chethan 2018). The performance of weeding tools is determined by their specific draft, energy requirements and the quality of works. Generally, cultivator and rotary tiller are used for weeding operation in Indian agriculture. Cultivator cut, dig the weeds and left over the surface and rotary tiller cut the weeds and also mix in soil. Rotary tiller (horizontal plough) rotates in vertical plane and impact on ground during weeding operation causes of increase soil resistance *i.e.* hard layer pan in line of crops row that may be prevent the leaching of water and nutrient to root zone of crops and effects the yield (Azadbhakt *et al.* 2014). The vertical rotary plough never creates hard pan at soil surface like horizontal rotary and gives better quality of soil. Soil resistance in vertical axis rotary plough is less and tilling quality is much more than horizontal one (Makange *et al.* 2015). Keeping the above sited problem, a non-powered self-propelling vertical axis inter row rotary weeder was developed which rotates in vertical axis to uproot, cut, mixes and cover the weeds in soil.

MATERIALS AND METHODS

Weeder development

A non-powered self-propelling vertical axis rotary weeder was developed at research laboratory of AgFE department, Indian Institute of Technology, Kharagpur. So many researchers have developed and evaluated the powered vertical axis rotary weeder for weeding under inter row cropping conditions, but very little have concentrated on the energy requirement aspect of the weeder (Makange and Tiwari 2015, Jakasania *et al.* 2017, Batista *et al.* 2018). A new concept of vertical axis rotary weeder, which is self-propelled by itself due to the motion of the tractor was developed. To cut the soil in vertical direction, a special type of trapezoidal shaped blades having the dimensions of 5×2×9 cm (a×b×h) was developed. These blades were made from boron steel having a hardness of 40-50 HRC. Total nine numbers of cutting blades were fixed to a specially developed rotary wheel unit and set at cutting angle of 45^0 to the direction of travel (**Figure 1**). At this cutting angle, the blades offers a complete coverage of the crops row. Later, the weeding unit was attached to a frame in vertical axis through bearing system and mounted on tractor with three point hitch system. The used bearing in an attachment offers no frictional resistance to the rotating unit. Further, there was no any other means of external power was provided to the rotary weeding unit to propel and cut the soil. During weeding operation, the cutting blades are engaged with soil and soil offers a frictional resistance to the cutting blades. When tractor starts to move in linear motion, the force acting in longitudinal direction caused by tractor movement generates a centrifugal force on rotary weeding unit, due to which the unit tends to self propel in perpendicular direction i.e.in vertical axis and cut the weeds and soil. Thus, requirement of external power to rotate the weeding unit was eliminated.

Field preparation

The testing of the developed weeders was conducted at the research farms. The field was prepared with help of tillage implement and well levelled. The soil samples were collected from the experimental sites to find the soil texture and test was conducted based on the USDA soil classification system (Azadbakht *et al.* 2014). It was found that soil texture was sandy loam. Before testing of the developed weeder in field condition it was prior tested in the soil-bin under different soil cone index varied from 300-500 kPa with rotary cutting blade depth from 2 to 6 cm.

Crop management and weeder testing

After soil-bin testing of the developed weeder, the different parameters were optimized such as number of blades, cutting angle, cutting depth, safety zone between plant stem to edge of rotary weeder, ground clearance of the weeding unit *etc* (**Table 1**). The hybrid maize crop was selected to test the developed weeder. A seed rate of 20 kg/ha was maintained and sown at 60 and 30 cm of row-to-row and plant-to-plant spacing during *Rabi*. A fertilizer dose of 150 kg of N, 70 kg of P and 70 kg of K was provided to the crops. Two stages of crop growth were selected such as crop at 15 and 30 days after sowing (DAS) to the test the weeder. It was ensured that, the weeder was passing at the centre of adjacent crop rows by maintaining a safety zone of 7 cm. Further, the weeder was also tested at two different depths such as 2 cm and 4 cm. The developed weeder was operated at forward speed of 1.6 and 2.25 km/h for 2 and 4 cm depth of operations

Table 1. Parameters optimized to develop vertical axis rotary weeder

Parameters		Optimized value
Number of blades		9
Width of cutting within a row, cm		46
Cutting angle of blade, degrees		45^0
Cutting depth, cm		2-4
Safety zone for weeder pass, cm		7
Ground clearance of weeding unit, cm	at 15 DAS	40
	at 30 DAS	90
Speed of operation, km/h		1.60
		2.25

respectively (speeds obtained in tractor at different gears). The different parameters such as, draft force required to weed out, field capacity, field efficiency, weeding efficiency, plant damage and cob yield was recorded based on the observations noted and also by using the formulas.

The draft force required by the implement was measured by using two tractor system, in which a load cell dynamometer was placed between the tractors and reading was noted (RNAM 1983, Smith *et al.* 1994). The power required to weeding, theoretical and actual field capacity (TFC and AFC), field and weeding efficiency (FE and WE) and plant damage (PD) were calculated based on the equations mentioned below (Smith *et al.* 1994, Chethan, 2013, Chethan and Krishnan 2017).

The power required to weeding at different speeds was calculated as follows.

$$Power\ (hp) = \frac{Draft\ (kg) \times Speed\ (kmh^{-1})}{270} \qquad (1)$$

The field efficiency is calculated as follows.

$$FE\ (\%) = \frac{TFC}{AFC} \qquad (2)$$

where,

$$TFC\ (hah^{-1}) = \frac{Mean\ working\ width\ (cm) \times Mean\ speed\ (ms^{-1})}{10000} \times 36 \qquad (3)$$

and

$$AFC\ (hah^{-1}) = \frac{Total\ area\ cultivated\ (ha)}{Total\ workingtime\ (h)} \qquad (4)$$

The plant damage is calculated as follows.

$$PD\ (\%) = \frac{P-Q}{P} \times 100 \qquad (5)$$

Where, P is the number of plants in a 10 m crop row length before weeding and Q is the number of plants in a 10 m crop row length after weeding.

Statistical analysis

The weed data were transformed into square root transformation($(\sqrt{x+0.5})$) to avoid the high variances of the values during statistical analysis. The study was conducted in split plot design and replicated thrice. The data was analyzed in ICAR-IASRI, New Delhi online statistical portal.

RESULTS AND DISCUSSION

The vertical axis rotary weeder was developed (**Figure 2**) and tested in the laboratory condition *i.e.* under soil bin at different soil cone index and operational depth. The operational environment at the field condition was recreated in soil bin to test the developed weeder for its prior settings and to optimize the operational parameters. A range of operational depth, blade cutting angle and cone index was selected under soil-bin test. The developed weeder was optimized for blade cutting angle of 45^0, operational depth of 2 to 4 cm and cone index of 300 to 500 kPa. At these parameters, the developed weeding unit was achieved a maximum area of coverage, which results

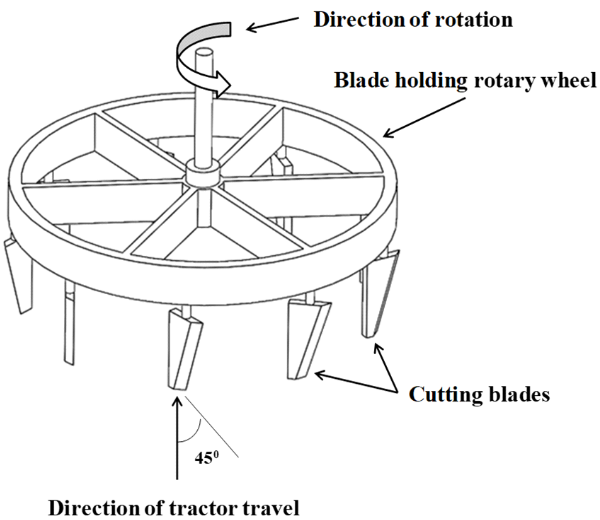

Figure 1. Working direction of the blades and rotary unit

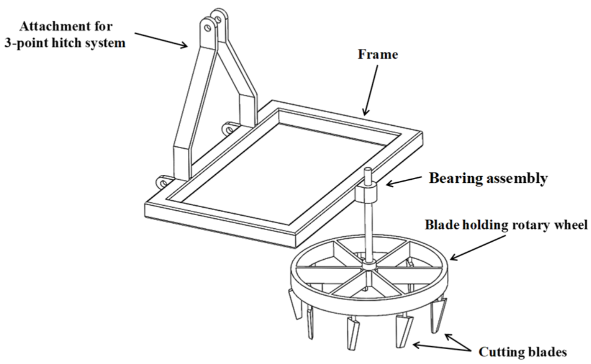

Figure 2. Developed vertical axis non-powered-self-propelling rotary weeding unit

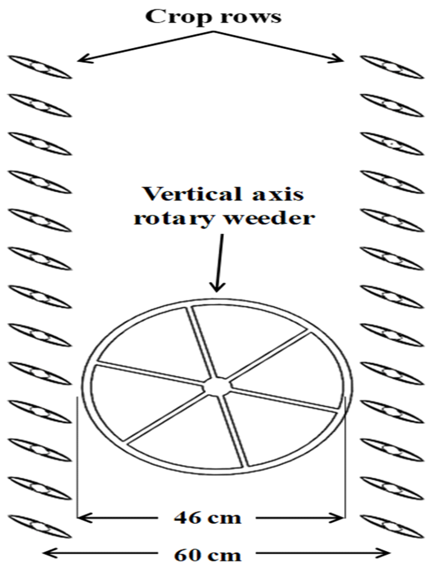

Figure 3. Schematic diagram of working operation of vertical axis rotary weeder

higher weeding efficiency. Therefore the same operational parameters were maintained during field testing at different crop growth stages. The rotary wheel and cutting blades adjustment was made such that, the weeding unit was able to achieve a working width of 46 cm for effective weed control. The developed weeder was operated in between the crops and maintained the position that, the unit must pass at the centre portion, so that, a safety zone of 7 cm *i.e.* distance between the edge of weeder rotary unit to the crop stem, was maintained to avoid damage to the crop stem and to the crop roots. The operational view of the developed weeder along with the safety zone is shown in **Figure 3**.

As discussed in the above portion, the developed weeder was tested at the maize field. Two crop growth stages *i.e.* 15 DAS and 30 DAS was selected for the testing. Five plant samples randomly taken within the test field to measure the crop height. The measured crop height at 15 DAS was up to 30 cm and at 30 DAS was up to 75 cm (**Figure 4**). At these stages the crop development was such that, a proper ground clearance was maintained in tractor and in the weeder attachment, thus crop damage due to dragging of lower portion of tractor body as well as the weeding unit was avoided. A proper lubrication in bearing system was done to ensure the free movement of the rotary unit, so that, the weeding unit will work efficiently. The cone index of the soil was measured and it was obtained in the range of 318 to 423 kPa by using a digital cone penetrometer. The measured cone index was within the optimized range, thus the weeder was tested.

The measured and calculated parameters such as the plant damage, weeding efficiency, field efficiency, actual field capacity, draft required to pull

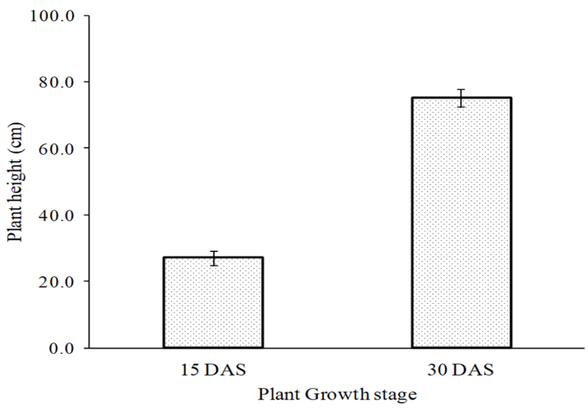

Figure 4. Height of maize crop at different growth stages

the weeder and cob yield recorded were statistically analyzed and given in the **Table 2**. The operation of developed weeder at different crop stages has a significant effect on plant damage, field capacity and efficiency and in cob yield. Whereas the operational depth significantly affects the field capacity and efficiency, weeding efficiency and draft force required to weed out the plants. However, on dependent parameter *i.e.* field capacity and field efficiency both operational depth and crop growth stage have significant effect. The highest plant damage of 5.88 % was observed in crop growth stage at 30 DAS (**Figure 5**). This highest value was achieved due to clogging of non-uniformly developed maize crop leaves to the weeding unit and restriction of the weeder movement within the row. This restricted movement of the weeding unit directly affects the time required to cover a unit area. Thus, a reduced actual field capacity and field efficiency was seen at 30 DAS compared to 15 DAS (**Figure 6**). Further, the plant damaged caused by the weeder at 30 DAS also affected the cob yield *i.e.* 12.20 t/ha, which was 5.4% lesser than the treatments at 15 DAS, but the draft force and power required to weeding was unaffected. In treatments having the 15 DAS offers minimal restriction to the weeder movement, therefore a very least plant damage value of 1.98% and higher cob yield of 12.9 t/ha was observed. This effect can be clearly seen in the figure.7. Therefore a proper ground clearance and care must be taken while weeding at higher growth stages of the crop. Always ensure a proper gap of 7 to 10 cm between machine body to the tip of the plant leaves to avoid plant damage.

As like in different crop growth stage treatments the similar type of effects are also in depth of operation treatments. As the operation depth was increased from 2 cm to 4 cm the forward speed of the tractor was reduced to overcome the problem of missing the weeds, abrupt throwing of the soil towards outside and longer tilling pitch. Even though

Table 2. ANOVA table for different parameters

Treatment	Plant damage (%)	Weeding efficiency (%)	Field efficiency (%)	Actual field capacity (ha/h)	Draft (kg force)	Cob yield (t/ha)
Operational depth (cm)						
2	3.92	73.87	80.03	0.08	6.30	12.63
4	3.94	64.89	57.97	0.04	7.89	12.47
LSD (p=0.05)	NS	1.20	11.91	0.01	0.08	NS
Crop growth stage (DAS)						
15	1.98	65.98	72.89	0.07	7.11	12.90
30	5.88	69.18	65.11	0.06	7.08	12.20
LSD (p=0.05)	3.86	NS	2.92	0.00	NS	0.30

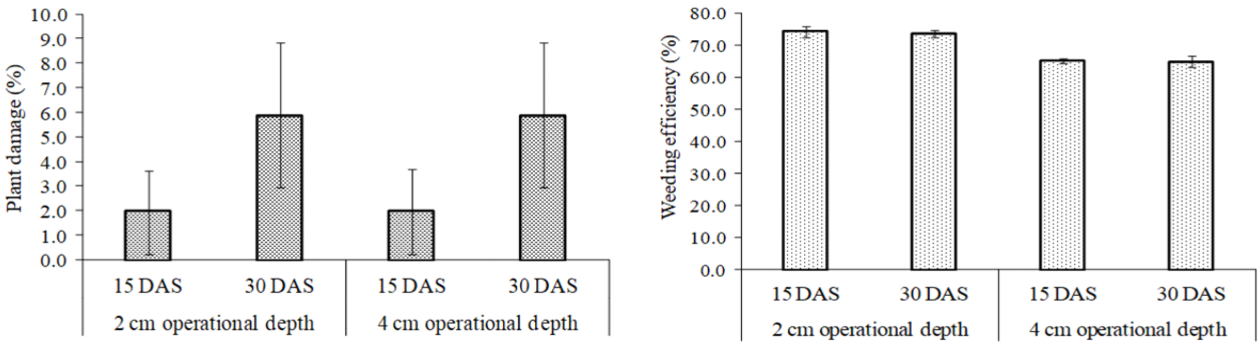

Figure 5. Plant damage and weeding efficiency obtained by weeder at different crop growth stages

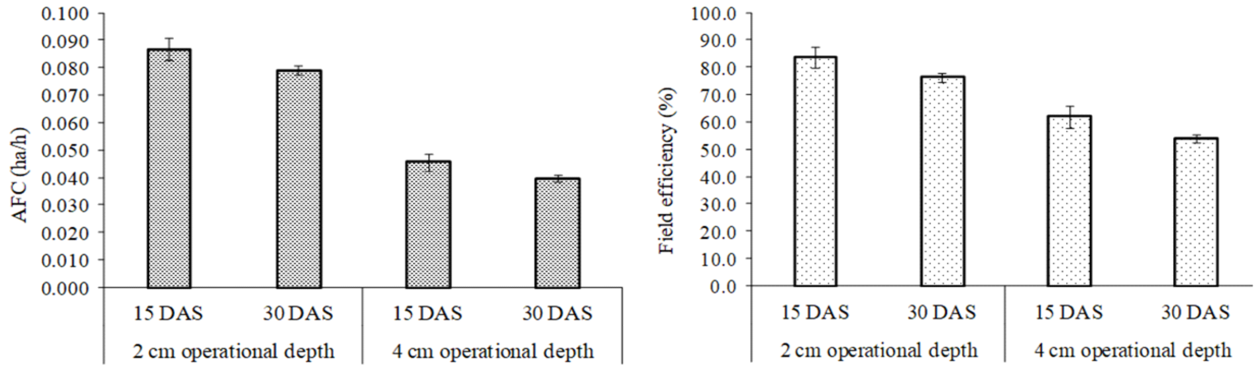

Figure 6. Actual field capacity and field efficiency of the weeder at different crop growth stages

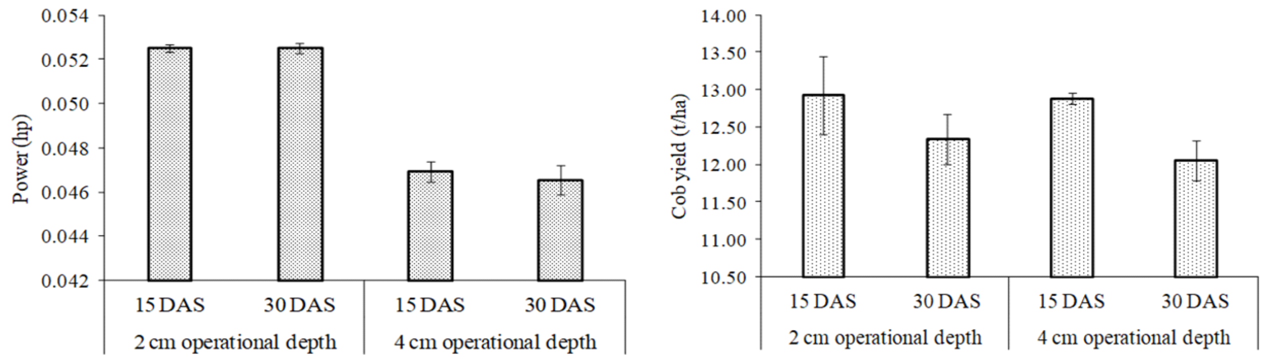

Figure 7. Power required by the weeder and cob yield obtained at different growth stages

the speed of operation reduced, some of the weed plants were escaped due to longer tilling pitch compared to the operational depth of 2 cm (speed of operation was 2.25 km/h). Thus, it affected the weeding efficiency, field efficiency and capacity, but does not have any effect on cob yield (**Figure 5**, **6** and **7**). It is obvious that, when the speed of operation reduces the field capacity will also automatically get reduced. The obtained values are 0.04 ha/h and 57.8% respectively for field capacity and field efficiency at operational depth of 4 cm, which was 27 to 50% lesser compared to the values obtained in treatments at operational depth of 2 cm. Further, the treatments having the operational depth of 2 cm achieved the higher weeding efficiency of 73.9% with higher field efficiency of 80%, higher field capacity of 0.08 ha/h and minimal draft requirement of 6.3 kg force. However, the plant damage was not significantly affected and obtained a value of around 3.9%. To obtain higher weeding efficiency with minimum plant damage and draft force requirement an operation depth of 2 cm can be adopted.

Non-powered self-propelling vertical axis rotary weeders can be developed without incurring an extra cost required for the external power unit to perform propelling and weeding operation. The developed weeders will match to all type of tractors ranging from lower horse power to higher horse power as it only requires draft force, that to in lower range. Therefore, with some modification according to the cropping conditions, the developed weeders can be used in different crops.

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Chemical weed control of dry direct-seeded rice under zero tillage in central mid-hill region of Nepal

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ABSTRACT

The performance of different herbicides for the weed control of dry direct-seeded rice (DDSR) under zero tillage was evaluated by field experiment during rainy season of 2017 at NARC, Lalitpur, Nepal. The treatments consisted of 8 different herbicidal treatments (pendimethalin 1.0 kg/ha, pendimethalin 1 kg/ha followed by bispyribac-Na 35 g/ha, pendimethalin 1.0 kg/ha followed by (*fb*) tank mix of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha, pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha, pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha, pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under co-culture with *Sesbania*) and a weedy check treatment with 3 replications under randomized complete block design. Result of the experiment revealed significant reduction in the weed density and increase in rice yield due to application of herbicides. Sequential application of pendimethalin (pre) *fb* tank mixture of pyrazosulfuron + bispyribac-Na (post) possess higher weed control efficiency and yielded the highest rice grain yield (3.78 t/ha), which was statistically at par with pendimethalin *fb* 2,4-D under Sesbania co-culture (3.44 t/ha) and pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha (3.09 t/ha). Similarly, application of pendimethalin 1.0 kg/ha (pre) *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha recorded the highest net returns of NRs. 31,760/ha and B: C ratio of 1.42 resulting to be the most economical and efficient herbicidal treatment option in DDSR under zero tillage.

Rice (*Oryza sativa L.*) is the world's second most important crop following maize, and is the major staple food for more than half of the world's population (Seck *et al.* 2012). Despite of the first position of rice in terms of area, production and consumption in Nepalese context, the present productivity remains very low *i.e.* 3.37 t/ha (MOALD 2017). This lower productivity of rice is not sufficient to meet the increasing demand of population over time. The major reasons are lack of improved cultivation practices, use of old generation seeds, lack of inputs like fertilizers, herbicides, insecticides, irrigation facility, inappropriate and improper weed management practices and poor access to infrastructure and market, *etc.* (Marahatta 2008).

The common method of rice cultivation in Nepal is by puddling followed by transplanting of 20-30 days old seedlings. However, there are several advantages of puddling like enhancing nutrient uptake (*e.g.* P, Fe, Zn) by creating anaerobic condition, reducing weed population (Singh *et al.* 2002), reduction in percolation loss and thus higher water use efficiency, facilitate transplanting and ease seedling establishment (Kirchhof *et al.* 2011). It adversely affects soil physical properties by dismantling soil aggregates, reducing permeability in subsurface layers (Sharma *et al.* 2003), forming hard-pans at shallow depths, which hinders the root development of other crops grown in rice based crop rotation and more emission of methane gas in atmosphere (Tripathi *et al.* 2005) and contributes to global warming (Gao *et al.* 2006). Therefore, the alternate method of planting *i.e.* Dry direct-seeded rice (DDSR) is gaining popularity regarding its high water, labour and energy use efficiencies (Kumar and Ladha 2011).

Dry-DSR is the methods of sowing dry seeds in the conventionally ploughed dry field. Direct-seeded rice removes puddling and drudgery of seedlings transplanting and provides an option to resolve the edaphic conflict, enhance the sustainability of rice based cropping system. DDSR rice matures 1-2 weeks earlier than transplanted rice, thus reducing the risk of terminal drought and allowing earlier planting of succeeding crop in rotation. However, researchers reported the lower yield under DDSR due to uneven or poor crop emergence, inadequate weed control, higher spikelet sterility than in puddled transplanting, higher crop lodging, especially in broadcasting and insufficient knowledge of water and nutrient management (micronutrient deficiencies). Weeds are the major constraint to the success of DSR in general and to DDSR in particular (Kumar *et al.* 2015). It is important to manage the weeds to sustain the yield with the adoption of DDSR. This study was planned and executed aiming to assist to evaluate the efficient and economically viable chemical weed control for higher productivity and profitability of rice under zero tillage DDSR system.

The field experiment was conducted at the Agronomy Farm of Nepal Agriculture Research Council (NARC), Khumaltar, Lalitpur, Nepal from June 2017 to November 2017. Geographically, the experimental site is situated at central Nepal (27^0 392 243 N, 85^0 192 353 E, 1300 masl.) with warm temperate climate. The total rainfall of 755.2 mm was received during the entire period of experiment. randomized complete block design (RCBD) with 9 treatments and 3 replications were set up while execution of the experiment. There were eight treatments regarding herbicides *i.e.* pendimethalin 1.0 kg/ha, pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha, pendimethalin 1.0 kg/ha *fb* tank mix of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha, pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha, pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha, pendimethalin 1.0 kg/ha followed by sulfosulfuron 30 g/ha, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under co-culture with *Sesbania* and a weedy check treatment. Khumal-10 variety of rice was sowed in a gross plot of 12 m^2 (3×4 m) on 7th June 2017. Manual sowing in a continuous line with 20 cm row-to-row distance in a zero tillage field was done. Harvesting was done on 25th October 2017 manually. Biometrical observations on plant height, leaf area index (LAI) and above ground biomass, different yield attributes, grain and straw yield, economics of yield as well as B: C ratio was calculated. Weed parameters, *viz.* weed density, weed index and weed control efficiency (WCE) were also measured. Collected data were analyzed using SPSS and ANOVA was done at 5% level of significance, whereas Microsoft excel was used for graph preparation.

Growth attributes

The taller plant was measured under plot treated with pendimethalin *fb* 2,4-D under *Sesbania* co-culture (136.1 cm) which was statistically superior with all the remaining treatments. Similarly, higher LAI was also found under plot treated with pendimethalin *fb* 2,4-D under *Sesbania* co-culture (2.23). The taller plant under *Sesbania* co-culture attained attractive growth because of nitrogen fixation by *Sesbania* along with smothering of weeds and conserving moisture and thus, more water and nutrients were available for the better growth and development, which resulted in superior growth of rice and hence higher plant height as well as LAI and this result was also agreed by Gaire *et al.* (2013). In pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha applied plots had produced higher above ground biomass (6.5 t/ha) while the lowest biomass was found under weedy check (4.3 t/ha), which was statistically at par with plots treated with pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha (4.7 t/ha), pendimethalin (4.9 t/ha), pendimethalin *fb* penoxsulam (5.3 t/ha) and pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture (5.7 t/ha). As intra-specific competition was same in every treatment, inter specific competition between crop and weeds affected the crop biomass. Ottis and

Table 1. Different growth and yield attributes of DDSR as influenced by application of different herbicidal matrices

Treatment	Plant height at harvest (cm)	Leaf area index (LAI)	Above ground biomass (t/ha)	Effective tillers/m^2	Panicle length (cm)	Filled grains/ panicle
Pendimethalin 1.0 kg/ha (pre)	117.5 ^{d}	2.15^{bc}	4.9 ^{cd}	133.3^{abc}	19.9 ^{b}	88.7^e
Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha	123.0 ^{bc}	2.13^{bc}	5.8 ^{abc}	114.3^{bc}	20.9 ^{b}	88.9^e
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha	118.8 ^{cd}	2.1^{bc}	6.2 ^{ab}	149.0^{ab}	21.5 ^{b}	108.6^c
Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	126.8 ^{b}	2.14^{bc}	4.7^{cd}	169.7^a	21.9 ^{b}	141.3^b
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha	124.4 ^{b}	2.13^{bc}	6.5^a	118.0^{bc}	20.8 ^{b}	105.9^c
Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha	125.8 ^{b}	2.09^c	5.3 ^{bcd}	142.3^{abc}	21.2 ^{b}	104.5^c
Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha	116.4 ^{d}	2.12^{bc}	5.5^{abc}	116.7^{bc}	19.4 ^{b}	96.9^d
Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	136.1 ^{a}	2.23^a	5.7^{bcd}	151.3^{ab}	24.7 ^{a}	178.1a
Weedy check	123.6 ^{b}	2.16^b	4.3^d	106.0 ^{c}	21.8 ^{b}	76.2^f
LSD (p=0.05)	4.263*	0.05446**	1.032**	33.16*	2.264*	6.68**

*Significant; **Highly significant. Treatment means followed by common letter(s) are not significantly different among each other based on DMRT at 5% level of significance

Talbert (2007) also stated that other things remaining constant, biomass productions depends upon intra and inter specific competition between the plants.

Yield attributes

Maximum effective tillers/m^2 was found under pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha (169.7) whereas the longest panicle was obtained under pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture (24.7 cm). Rest of the treatments was comparable to each other. Statistically similar result was obtained for number of filled grains/panicle in plots treated with pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 35 g/ha, pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha and pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha + byspyribac-Na 25 g/ha. Weedy check plot produced the least number of grains/panicle. Higher the weed density caused the lower effective tillers and lesser filled grains per panicle. Weedy check plot produced the least number of grains/panicledue to the presence of weeds throughout the crop cycle, which caused the depletion of nutrient and less absorption of nutrients by the crop especially during grain filling period. Ehsanullah *et al.* (2014) also reported higher effective tillers per square meter in herbicide applied plot.

Grain and straw yields and sterility

The use of different herbicidal matrices has significantly influenced the grain and straw yield, and sterility percentage (**Table 2**). The highest grain yield (3.78 t/ha) was observed in pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha and was statistically similar with the yield of pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture (3.44 t/ha), pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha (3.35 t/ha) and pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha (3.09 t/ha). The lowest yield was obtained under weedy check plots which might be due to competition from weeds, which reduced LAI and allowed less light transmission producing less biosynthate and ultimately low dry matter production (Parameswari YS and Srinivas A. 2014). Similarly, the highest straw yield was recorded in pendimethalin 1.0 kg/ha *fb* tank mixture of pyrzosulfuron 20 g/ha + bispyribac-Na 25 g/ha (6.5 t/ha), which was statistically at par with pendimethalin *fb* pyrazosulfuron (5.86 t/ha). The weedy check produced the lowermost straw yield (3.39 t/ha), which was statistically at par with pendimethalin 1.0 kg/ha (3.97 t/ha). Parameswari and Srinivas (2014) stated that the huge amount of nitrogen, phosphorous and potassium was removed by the weeds in weedy check plot resulting in lower uptake of nutrients by rice causing low biomass yield.

The average sterility percentage during the experiment was observed to be 8.99% ranging from 7.01% in pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha to 12.66% in pendimethalin 1.0 kg/ha treated plot. Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha resulted in lowest sterility (7.01%), which was statistically at par with pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha (7.02), pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture (8.24%), and pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha and bispyribac-Na 25 g/ha (8.43%). The effect of application of herbicides was non-significant to thousand grains weight.

Economics

The cost of cultivation, gross return, net return and B:C ratio as affected by various herbicidal treatments has been presented in **Table 3**. The cost of cultivation was higher for pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under *Sesbania* co-culture. Significantly higher gross return, net return and B:C ratio was found under pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha and bispyribac-Na 25 g/ha.

Table 2. Yield and yield attributes as influenced by different herbicidal matrices application

Treatment	Straw yield (t/ha)	Grain yield (t/ha)	Sterility (%)
Pendimethalin 1.0 kg/ha (pre)	3.97 ^{ef}	1.63 ^{cd}	12.7 ^{a}
Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha	4.90 ^{cd}	2.58 ^{bc}	9.2 ^{b}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha	6.50 ^{a}	3.78 ^{a}	8.4 ^{bc}
Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	4.70 ^{cde}	2.42 ^{bc}	7.0 ^{c}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha	5.86 ^{ab}	3.35 ^{ab}	7.0 ^{c}
Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha	4.66 ^{cde}	3.09 ^{ab}	9.5 ^{b}
Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha	4.50 ^{de}	2.13 ^{bc}	9.6 ^{b}
Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	5.49 ^{bc}	3.44 ^{ab}	8.2 ^{bc}
Weedy check	3.39 ^{f}	0.97 ^{d}	9.2 ^{b}
LSD (p=0.05)	0.799**	1.09**	1.491**

*Significant; **Highly significant. Treatment means followed by common letter(s) are not significantly different among each other based on DMRT at 5% level of significance

Weed density and weed control efficiency

Different herbicidal treatments significantly reduced the weed density and contributed in the higher grain yield as compared to weedy check. Weed density was increasing up to 30 DAS and started to reduce thereafter mainly due to application of herbicides in the field. Total weed density (narrow, broadleaf and sedges) was found to be higher under weedy check. At 30 DAS, total weed density was the lowest under pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha (183.5 no./m^{2}). Similarly, at 60 DAS, the lowest weed density was found with pendimethalin 1.0 kg/ha *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha (70.5 no./m^{2}) as compared to other treatments (**Table 4**). The lower weed density in this plot may be due to the better and broad spectrum weed control by applying two different herbicides. WCE also significantly influenced by different herbicidal application (**Table 4**). At 30 DAS, WCE was the highest with pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha (20.56%) and the lowest with pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha under co-culture with *Sesbania*. At 60 DAS, WCE in the plot treated with pendimethalin 1.0 kg/ha *fb* y tank mix application of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha was the highest (43.36%), which was also agreed by Kumar *et al.* (2017) while being lowest in the plot with pendimethalin 1.0 kg/ha (21.72%). Similar results were also found by Rao (2005) and Nayak *et al.* (2014) who reported a variable weed control in paddy field with the use of different herbicidal treatments.

Weed index

The weed index ranged the lowest with pendimethalin *fb* tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha (-2.23%) to the highest in weedy check plot (58.13%). It means the reduction in yield due to presence of weed was 58.13% in the experiment. Sharma (2013) also reported that 65% yield reduction in DDSR was due to weed in Chitwan condition. Weedy check produced the higher weed index as compared to other treatments due to presence of invasive (species that is not native to a specific location) number of weeds as never removed from the plot that was statistically at par with the pendimethalin treated plot.

Table 3. Economic analysis on cost of cultivation, gross return, net return and B:C ratio as influenced by different herbicidal matrices application

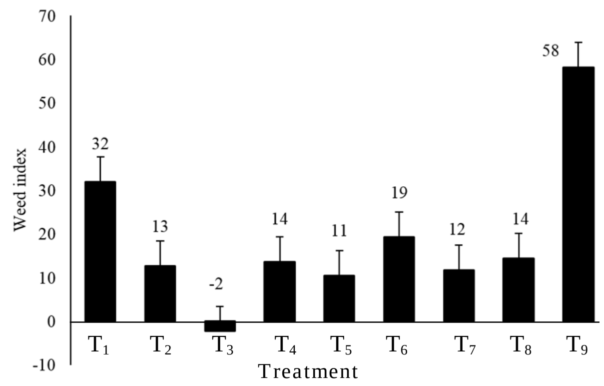
Treatment	Total cost of cultivation (x10^{3} `/ha)	Gross return (x10^{3} `/ha)	Net return (x10^{3} `/ha)	B:C ratio
Pendimethalin 1.0 kg/ha (pre)	67.47^{g}	92.29^{f}	24.31^{c}	1.36^{c}
Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha	73.31^{d}	103.47^{b}	30.16^{b}	1.41^{b}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha	75.64^{b}	107.40 ^{a}	31.76^{a}	1.42^{a}
Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	74.53^{c}	95.39e	20.86^{f}	1.28^{f}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha	73.24^{d}	96.46^{d}	23.22^{d}	1.32^{d}
Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha	72.28^{e}	95.26^{e}	22.98^{d}	1.32^{d}
Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha	74.74^{c}	96.67^{d}	21.93^{e}	1.29^{e}
Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	76.31^{a}	101.06^{c}	24.74^{c}	1.32^{d}
Weedy check	64.47^{g}	51.60^{g}	-12.87^{g}	0.81^{g}
LSD (p=0.05)	0.5740**	0.4948**	0.7170**	0.0116**

*Significant; **Highly significant. Treatment means followed by common letter(s) are not significantly different among each other based on DMRT at 5% level of significance

Table 4. Weed density and weed control efficiency as influenced by different herbicidal matrices application

Treatment	Weed density (no./m^{2})		Weed control efficiency (%)	
	30 DAS	60 DAS	30 DAS	60 DAS
Pendimethalin 1.0 kg/ha (pre)	249.2 ^{b}	141.1 ^{b}	12.4 ^{bc}	21.7 ^{e}
Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha	197.2 ^{d}	92.9 ^{e}	20.6 ^{a}	36.6 ^{b}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha	183.5 ^{e}	70.5 ^{g}	11.20 ^{c}	43.4 ^{a}
Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	206.0 ^{cd}	101.7 ^{d}	14.1 ^{bc}	32.4 ^{c}
Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha	203.9 ^{d}	112.7 ^{c}	16.1 ^{b}	33.3 ^{c}
Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha	218.1 ^{c}	102.2 ^{d}	12.9 ^{bc}	27.5 ^{d}
Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha	195.5 ^{de}	78.3 ^{f}	13.9 ^{bc}	37.2 ^{b}
Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha	208.9 ^{cd}	78.9 ^{f}	11.2 ^{c}	32.9 ^{c}
Weedy check	317.5 ^{a}	169.4 ^{a}	-	-
LSD (p=0.05)	13.01 **	7.099**	3.383 *	1.034 **

*Significant; **Highly significant. Treatment means followed by common letter(s) are not significantly different among each other based on DMRT at 5% level of significance



T_1- Pendimethalin 1.0 kg/ha; T_2- Pendimethalin 1.0 kg/ha *fb* bispyribac-Na 35 g/ha; T_3- Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha; T_4- Pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha; T_5- Pendimethalin 1.0 kg/ha *fb* pyrazosulfuron 20 g/ha; T_6- Pendimethalin 1.0 kg/ha *fb* penoxsulam 14 g/ha; T_7- Pendimethalin 1.0 kg/ha *fb* sulfosulfuron 30 g/ha; T_8- Co-culture with *Sesbania*, pendimethalin 1.0 kg/ha *fb* 2,4-D 1.0 kg/ha; T_9- Weedy check

Figure 1. Weed index of different herbicidal matrices application

It was concluded that the herbicides contributed significantly to the growth and yield of the crop by providing adequate weed control and, hence, reducing the competition occurred by dense weed growth. Pre-emergence application of pendimethalin 1.0 kg/ha followed by application of tank mixture of pyrazosulfuron 20 g/ha + bispyribac-Na 25 g/ha as post-emergence herbicide was found effective to control against diverse weed flora, produced higher grain yield and proved to be more economic in return in dry direct seeded rice. It could be advocated that the chemical weed control in dry DSR would be a new direction for research and development in Nepalese rice production system.

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Herbicide mixtures for weed management in wet-seeded rice

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ABSTRACT

Three herbicidal mixtures, *viz*. triafamone 20% + ethoxysulfuron 10% (pre-mix) 67.5 g/ha, 12 days after sowing (DAS), cyhalofop-butyl+ penoxsulam 6% OD (pre-mix) 150 g/ha, 20 DAS, and fenoxaprop-p-ethyl 6.9 EC 60 g/ha+ ethoxysulfuron 15 WDG (tank mix) 15 g/ha, 20 DAS were evaluated for their efficacy against weeds in wet-seeded rice. These treatments were compared with bispyribac-sodium, hand weeding twice and unweeded control. Application of triafamone + ethoxysulfuron, and cyhalofop-butyl + penoxsulam, significantly reduced the weed biomass followed by the treatments bispyribac-sodium, and hand weeding at 60 DAS. Fenoxaprop-p-ethyl + ethoxysulfuron had significantly lower weed control efficiency, probably due to its inability to control *Echinochloa crus-galli* effectively. Considering rice grain and straw yields, all herbicide treatments were at par except for fenoxaprop-p-ethyl + ethoxysulfuron, which recorded significantly lower values. Among yield attributes, significantly higher number of panicles/ m^2 was recorded in the treatments triafamone + ethoxysulfuron, and hand weeding, followed by cyhalofop-butyl+ penoxsulam. Grain and straw yields were lowest in unweeded control.

Weed complexes in rice are difficult to control as they include grasses, sedges and broad leaf weeds. Single application of a pre- or post-emergence herbicide cannot control the wide array of weeds present in direct-seeded rice. Broad-spectrum herbicides can control most of these weeds, but there are tolerant species which are susceptible only to specific herbicides. Application of weed specific herbicides in sequence to manage all types of weeds is neither practical nor economic. Herbicide mixtures would be more acceptable option as the operation would be completed in a single application and would save time. Several new pre-mix herbicides are now available, the efficacy of which have been less studied and which could manage the weed populations to acceptable levels. However, the weed species present, which depends on the climate, soil and environmental conditions, would determine the weed control efficiency. Three herbicide mixtures were evaluated in the Agricultural Research Station, Mannuthy, Thrissur in Kerala to study their action against a mixed population of weeds and also to assess their effects on growth and yield of rice.

The experimental site is located at 12^0 32' N latitude and 74^0 20' E longitude at an altitude of 22.25 m above MSL. The soil is sandy loam in texture and has a pH of 5.84. The experiment was conducted in *Kharif*, 2018. The crop was wet-seeded on 10-07-18 and harvested on 1-10-18. The experiment consisted of six treatments laid out in randomised block design with four replications. The rice variety cultivated was '*Jyothi*' and the gross plot size was 20 m^2. The treatments were: triafamone 20% + ethoxysulfuron 10% (pre-mix) 67.5 g/ha at 12 days after sowing (DAS), cyhalofop-butyl + penoxsulam 6% OD (pre-mix) 150 g/ha at 20 DAS, fenoxaprop-p-ethyl 6.9 EC 60 g/ha+ ethoxysulfuron 15 WDG (tank mix) 15 g/ha at 20 DAS, bispyribac-sodium 25 g/ha at 20 DAS, hand weeding twice at 20 and 40 DAS and an unweeded control.

Weed flora

The major weed flora of the field included *Echinochloa crus-galli* and *Ludwigia perennis*. *Hydrolea zeylanica*, *Phyllanthus niruri*, *Eclipta alba* and *Scoparia dulcis* were minor weeds. At 30 DAS, weed density was not affected by treatments except in the case of *Echinochloa crus-galli* and *Eclipta alba* (**Table 1**).

Echinochloa crus-galli density was highest in unweeded control, and lowest in the treatment triafamone + ethoxysulfuron. Bispyribac-sodium

Table 1. Effect of treatments on weed density at 30 DAS

Treatment	Weed density (no./m^2)					
	Echinochloa crus-galli	*Eclipta alba*	*Ludwigia perennis*	*Hydrolea zeylanica*	*Phyllanthus niruri*	*Scoparia dulcis*
Triafamone + ethoxysulfuron	*0.22(0)	4.13 (17.3)	1.10 (2.7)	0.82 (1.3)	0.82 (1.3)	0.82 (1.3)
Cyhalofop-butyl + penoxsulam	3.62 (13.3)	3.65(13.3)	1.10 (2.7)	0.22 (0)	0.22 (0)	0.22 (0)
Fenoxaprop + ethoxysulfuron	4.21 (20.0)	0.82(1.3)	0.22 (0)	0.22 (0)	0.22 (0)	0.22 (0)
Bispyribac-sodium	2.18(6.7)	0.22 (0)	1.48 (5.3)	0.22 (0)	0.22 (0)	0.22 (0)
Hand weeding	4.67 (25.3)	0.22(0)	0.22 (0)	0.22 (0)	0.22 (0)	0.22 (0)
Unweeded control	6.68 (44.7)	1.31 (4)	1.97 (5.3)	0.22 (0)	0.22 (0)	0.22 (0)
LSD (p=0.05)	2.23	1.83	NS	NS	NS	NS

*($\sqrt{x+1}$) transformed values; Original values are given in parentheses

application was at par with this treatment. *Eclipta alba* density was found to be significantly higher in the treatments triafamone + ethoxysulfuron, and cyhalofop-butyl + penoxsulam at this stage.

At 60 DAS, only two weeds were seen in the field, *viz. Echinochloa crus-galli* and *Ludwigia perennis* (**Table 2**). Of these two, *Ludwigia perennis* was found not significantly affected by treatments. Significantly higher density of *Echinochloa crus-galli* was seen in unweeded control. Lowest density was seen in the treatment triafamone + ethoxysulfuron, and this treatment was on par with hand weeding. This was followed by other herbicidal treatments, which were on par.

Table 2. Effect of treatments on weed density at 60 DAS

Treatment	Weed density (no./m^2)	
	Echinochloa crus-galli	*Ludwigia perennis*
Triafamone + ethoxysulfuron	*2.29(5.3)	0.22 (0)
Cyhalofop-butyl + penoxsulam	3.74(14.7)	0.22 (0)
Fenoxaprop + ethoxysulfuron	4.42(20.0)	0.22 (0)
Bispyribac-sodium	4.13(17.3)	0.22 (0)
Hand weeding	3.16(10.7)	0.22 (0)
Unweeded control	7.26(52.7)	0.82 (1.3)
LSD (p=0.05)	1.446	NS

*($\sqrt{x+1}$) transformed values; Original values are given in parentheses

Table 3. Effect of treatments on weed biomass and weed control efficiency

Treatment	Weed biomass (kg/ha)		Weed control efficiency (%)
	30 DAS	60 DAS	60 DAS
Triafamone + ethoxysulfuron	*18.3(3)	56.6(32)	92.3
Cyhalofop-butyl + penoxsulam	57.8(40)	69.7(50)	88.0
Fenoxaprop + ethoxysulfuron	62.7(44)	170.5(291)	30.0
Bispyribac-sodium	29.7(12)	87.5(77)	81.6
Hand weeding	65.2(56)	87.6(81)	80.7
Unweeded control	49.4(24)	204.3(418)	-
LSD(p=0.05)	NS	27.25	-

*($\sqrt{x+1}$) transformed values; Original values are given in parentheses

Weed biomass

Data on weed dry matter production are presented in **Table 3**. At 30 DAS, effect of treatments was non-significant. But at 60 DAS, the treatment triafamone + ethoxysulfuron was significantly better in reducing weed growth. Triafamone + ethoxysulfuron was reported to bring about lowest weed count and weed dry matter at 42 days after application by Deivasigamani (2016). Cyhalofop-butyl + penoxsulam was at par with this treatment. Kailkhura *et al.* (2015) also reported the efficacy of ready-mix of cyhalofop butyl+ penoxsulam in reducing weed biomass. Treatments bispyribac-sodium and hand weeding came next, while fenoxaprop-p-ethyl + ethoxysulfuron was significantly inferior to other herbicide treatments. Highest weed biomass was recorded in the unweeded control. At 60 DAS, highest weed control efficiency was recorded in the treatment triafamone + ethoxysulfuron (92%), followed by cyhalofop-butyl + penoxsulam (88%). Other treatments also recorded weed control efficiencies greater than 80% except for fenoxaprop-p-ethyl + ethoxysulfuron, which had considerably lower efficiency. This is contrary to the results of Tiwari *et al.* (2010) who noticed the highest weed control efficiency on mixing fenoxaprop-p-ethyl with ethoxysulfuron.

The results showed that the pre-mix herbicide mixtures were highly effective in controlling weed growth as compared to the popularly used bispyribac-sodium, and even to hand weeding. However, fenoxaprop-p-ethyl + ethoxysulfuron had significantly less effect, probably due to the inability of fenoxaprop-p-ethyl to control *Echinochloa crus-galli* effectively.

Rice yield and yield attributes

Higher rice grain yields were obtained in treatments with lower weed dry matter production (**Table 4**). All herbicide treatments were at par except

Table 4. Effect of treatments on yield and yield attributes

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	No. of panicles/m	No. of grains/panicle	No. of filled grains /panicle	1000 grain weight (g)
Triafamone + ethoxysulfuron	3.80	5.98[a]	121.67	104.00	94.33	29.60
Cyhalofop-butyl + penoxsulam	3.67	5.97[a]	110.66	115.00	87.00	29.20
Fenoxaprop + ethoxysulfuron	2.52	4.99	92.00	97.33	72.67	27.67
Bispyribac-sodium	3.17	5.90	98.33	116.33	92.00	29.93
Hand weeding	3.62	5.30	120.67	115.67	93.00	28.97
Unweeded control	1.96	3.95	63.67	99.00	62.67	26.20
LSD (p=0.05)	0.71	0.50	8.52	NS	21.76	1.74

for fenoxaprop-p-ethyl + ethoxysulfuron, which recorded significantly lower grain yields. Straw yields followed the same trend as grain yields, with the treatment fenoxaprop-p-ethyl + ethoxysulfuron resulting in significantly lower value, although it was on par with hand weeding. Lowest grain and straw yields were observed in unweeded control.

Number of panicles/m^2 differed significantly with highest values recorded in the treatments triafamone + ethoxysulfuron and hand weeding. Number of grains per panicle were not significantly affected by treatments. However, all treatments were found to be significantly superior to unweeded control with respect to number of filled grains per panicle. This was true when considering 1000 grain weight also. Comparing the herbicide mixtures, the treatment fenoxaprop-p-ethyl + ethoxysulfuron resulted in significantly lower grain yield, which could be related to the lower number of panicles/m^2. Higher weed competition might have caused lower panicle production, which adversely affected the yield. The 1000-grain weight, was also seen to be lower in this treatment, though the effect was not statistically significant.

The study shows that mixtures of herbicides applied in one dose are effective in managing weed populations, thereby leading to yields at par with hand weeding. Moreover, if climatic factors make the application of a pre-emergence herbicide difficult, a mixture of herbicides applied at a later stage would still control weeds effectively and produce high yields. An added advantage is that applications of different herbicides as a tank mixture may prove helpful in delaying the problem of herbicide resistance as well as a shift in weed flora, which is invariably associated with the use of a single herbicide (Wrubel and Gressel 1994).

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Planting method, row arrangement and crop residue mulch influence on weed dynamics and productivity of toria mustard

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ABSTRACT

A field study was conducted at ICAR-Research Complex for NEH Region, Basar during 2012-13 to study the effect of planting methods, row arrangement and mulching on toria (*Brassica campestris* L.) and associated weeds. Results revealed that at 30 and 60 days after sowing (DAS), the weed density and weed dry biomass were lesser in ridge and furrow; among row arrangement lower weeds at 6 rows followed by 3 rows over normal row planting. However, between the mulch, at 30 DAS the lower density and dry biomass were recorded with groundnut haulm mulching at 4 t/ha over no mulch, whereas at 60 DAS, dramatically no mulch plots had lesser weeds as compared to mulched plots. The number of branches/plant, siliqua/plant, seeds/siliqua, seed and stover yields were higher in ridge and furrow at 6 rows arrangement with groundnut haulm mulch at 4 t/ha.

Oilseeds are the second largest agricultural commodities in India next to cereals. The oilseed requirement in India has been significantly increased and among oilseed crops rapeseed and mustard is major contributor. During 2015-16, the rapeseeds and mustard has been grown in an area of 5.76 million ha with production of 6.82 million tonne and the productivity was 1184 kg/ha (Anonymous 2017). Toria (*Brassica campestris* L.) belongs to the group of rapeseed and mustard, perform best in the winter season and are a potentially valuable crop in rainfed condition. However, weeds are major biological constraints in toria production; the losses due to weeds vary from 20-30% (Singh *et al.* 2010). Weeds compete with crop for available resources, *viz*. space, light, nutrients, water *etc*. and the competition is more serious during early stages due to slow growth during the first 4-6 weeks after sowing. It has also been reported that if weeds are abandoned, are capable of reducing yield even more than 80% (Singh *et al.* 2012) and up to 76.3% (Kumar *et al.* 2012) in Indian mustard.

In humid climate, weeds are major production constraints. Yield losses due to weeds can be minimized using locally available crop residue as mulch material (Choudhary *et al.* 2013 and 2016). Mulch with crop residues has a significant effect on weed suppression, nutrient uptake, thermal regulation, water retention and higher microbial activities (Choudhary and Kumar 2018). Use of legume mulch has a faster rate of decomposition, thus may not provide long duration weed-free condition as cereals but can provide a considerable effect on growth and productivity. Similarly, alteration in land configuration influence the weed composition, growth and productivity, which has been documented in maize-frenchbean-toria cropping system (Choudhary 2016). Change in row arrangement of a crop may provide weed suppression due to closure planting and have better growth of either side of the row plants. However, there is limited information available on the effect of groundnut mulch, planting methods and row arrangement on weed suppression and productivity on toria mustard. Therefore, an attempt was made to study the effect of planting methods, row arrangement and mulch on toria in the fragile North Eastern Himalayan agro-ecosystem.

A field study was conducted during 2012-13 at ICAR, Research Complex for NEH Region, Basar, Arunachal Pradesh (27° 95′ N latitude and 94° 76′ E longitude, 664 m above mean sea level). The soil characteristics of the site were acidic in nature (pH 5.7) with high in organic carbon (0.87%), low in available nitrogen (210.5 kg/ha) and phosphorus (7.8 kg/ha) and high in available potash (310.5 kg/ha). The experiment was laid out in factorial randomized block design (FRBD) and replicated thrice. The gross plot size of the smallest unit was 3 × 3 m. There were three factors *i.e.* planting method (flat bed and ridge and furrow), row arrangement [normal (30 × 10 cm), 3 rows (20 × 20 × 50 cm) and 6 rows (20 × 20 × 20 × 20 × 20 × 80 cm)] and mulching (no mulch and mulching with groundnut haulm at 4 t/ha). Toria seeds (5 kg/ha) of variety '*TS-38*' were sown on 28 October 2012 with recommended package of practices except the treatment variability. Crop was applied with recommended dose of fertilizer *i.e.* 60:30:30 kg N, P_2O_5 and K_2O/ha. The crop was harvested on 15 February 2013.

Data on various yield attributes were recorded by randomly taking five tagged plants from each plot. The seed yield of toria was recorded at maturity and seed moisture content was adjusted to 9% while calculating final yield. To record the weed density, weeds were pulled out from the 0.5 × 0.5 m quadrate at 30 and 60 days after sowing (DAS) and grouped into broad-leaved, grassy weeds and sedges. Further, weed roots and soil particle adhere were separated from the plant and kept in an oven at 70±1°C for 72 hours till constant weight was observed and this was considered weed dry biomass. The weed data (weed density and dry biomass) were subjected to square root transformation ($\sqrt{x+0.5}$). The weed suppression efficiency (WSE) was recorded as per the standard formula suggested by Choudhary *et al.* (2018).

$$WSE (\%) = [(WDB_{control} - WDB_{treatment})/WDB_{control}] \times 100$$

where, $WDB_{control}$, weed dry biomass in normal sowing in flatbed with no mulch plot; $WDB_{treatment}$, weed dry biomass in treatment imposed plots

The data were subjected to statistical analysis using SAS 9.2 (SAS Institute, Cary, NC). The significance of the treatment was determined by the F-test and the difference between means was compared using the critical difference (CD) at 5% probability level. The interactions between factors were non-significant.

Effect on weed density and dry biomass

The study area comprised with broadleaved weeds *i.e. Ageratum conyzoides, Galinsoga parviflora, Commelina benghalensis, Chromolaena odorata* and *Borreria hispida* and grasses *i.e. Digitaria sanguinalis, Eleusine indica, Dactyloctenium aegyptium, Echinochloa colona* and *Cynodon dactylon* etc. whereas; *Cyperus rotundus* was only sedge present. At 30 DAS, between planting method, flat bed recorded the highest broad-leaved weeds, grasses and sedge by 21.3, 33.6 and 28.4%, respectively over ridge and furrows. Among row arrangement, the lowest weeds were recorded in 6 row arrangements by 25.2, 15.6 and 13.4% followed by 3 rows by 18.1, 11.4 and 12.4%, respectively over normal row planting. Between mulching, placement of mulch recorded 49.1, 20.5 and 27.3% lower weed density over no mulch. Reduction in group-wise weed density resulted in the lowering of total weed density by 22.6% in ridge and furrow, 60.7 and 22.0% in 6 and 3 rows arrangement and 40.2% in mulched plots over others (**Table 1**).

Weed dry biomass followed the trend of weed density and recorded lower weed dry biomass of broad-leaved, grasses and sedge in ridge and furrow by 30, 30.4 and 35.8%, respectively over flat bed. In 6 row arrangements, these were reduced by 30.7, 16.6 and 13.8%, respectively over normal planting, and 3 row arrangement lowered by 22, 10.9 and

Table 1. Effect of planting methods, row arrangement and mulching on weed density, weed dry biomass and weed suppression efficiency at 30 DAS in toria

Treatment	Weed density (no./m^2)				Weed dry biomass (g/m^2)				WSE
	BLW	Grasses	Sedge	Total	BLW	Grasses	Sedge	Total	(%)
Planting method									
Flat bed	6.0(37.1)*	3.8(14.3)	3.0(8.6)	7.7(60.0)	3.3(11.3)	3.0(8.7)	2.3(4.7)	5.0(24.7)	29.5
Raised bed	5.4(29.2)	3.4(11.1)	2.6(6.2)	6.8(46.4)	2.8(7.9)	2.5(6.0)	1.9(3.0)	4.1(17.0)	51.6
LSD(p=0.05)	0.28	0.09	0.09	0.23	0.15	0.07	0.06	0.11	
Row arrangement									
Normal	6.2(38.8)	3.8(13.9)	2.9(8.1)	7.8(60.8)	3.4(11.6)	2.9(8.1)	2.2(4.2)	4.9(23.9)	31.6
3 rows	5.6(31.8)	3.6(12.3)	2.7(7.1)	7.1(51.2)	3.0(9.1)	2.8(7.2)	2.0(3.7)	4.5(20.0)	42.8
6 rows	5.3(29.0)	3.5(11.8)	2.7(7.0)	6.9(47.8)	2.8(8.1)	2.7(6.8)	2.0(3.6)	4.3(18.5)	47.2
LSD (p=0.05)	0.35	0.11	0.11	0.28	0.18	0.09	0.08	0.13	
Mulching									
No mulch	6.6(43.9)	3.8(14.1)	3.0(8.6)	8.2(66.6)	3.7(13.2)	2.9(8.3)	2.2(4.5)	5.1(26.0)	25.7
Mulch at 4 t/ha	4.7(22.4)	3.4(11.2)	2.6(6.2)	6.3(39.8)	2.5(5.9)	2.6(6.4)	1.9(3.2)	4.0(15.6)	55.4
LSD (p=0.05)	0.28	0.09	0.09	0.23	0.15	0.07	0.06	0.11	-

BLW= Broad-leaf weeds; WSE= Weed smothering efficiency; *Figures in parentheses are original means and data are subjected to square root transformation

11.4%, respectively. The total weed dry biomass was 31.2% lower in ridge and furrow (17.0 g/m^2) than flat beds. Among row arrangements, 6 rows have total weed dry biomass lesser by 22.9% (18.5 g/m^2) followed by 3 rows by 16.4% (20 g/m^2) over normal row planting. Between mulching, placement of mulch reduced the weed dry biomass by 40.0% (15.6 g/m^2) over no mulch. Lower weed density and dry biomass helped in achieving higher weed suppression efficiency (WSE) in ridges and furrow by 22.1% over flat bed, whereas, 6 rows arrangement had 15.6% and 3 rows had 11.2% lower WSE than the normal planting. Between mulches, placement of mulch recorded 297% lower weed suppression over no mulch.

At 60 DAS, a weed density and dry biomass followed the similar trend of 30 DAS. However, between planting methods, ridge and furrow recorded considerably lesser broad-leaf weeds by 34.6 and 43.3%, grasses by 44.2 and 51.9% and sedge by 29.2 and 39.0%, respectively which was considerably more than of 30 DAS. Among row arrangement, with progress in crop duration there was an increase in weed density of broad-leaf, grasses and sedge, however, at 6 rows it was lower by 20.5 and 28.6%, 27.4 and 34.1%, 16.4 and 24.7%, respectively and in 3 rows it was 15.6 and 16.2%, 14.7 and 17.1%, 6.0 and 24.7%, respectively over normal row planting. Between mulch, the weed density of broad-leaved and sedge was dramatically increased in a mulched plot by 32.7 and 23.4%, 21.7 and 10.0%, respectively whereas, grasses were lower by 32.9 and 41.3%, respectively. This resulted in an overall reduction of weed density by 23.8% and 8.4%, respectively in no mulch (**Table 2**). The more density and dry biomass were mainly due to the progress in crop duration, the placed mulch started decomposing and the land area gets exposed resulted in more and more emergence and establishment of weeds. Similarly, the release of plant nutrients from groundnut haulm further intensified the growth and development of weeds (Choudhary 2016). Hence, poor weed suppression obtained in groundnut haulm mulched plots at later sampling time. Under such condition, the use of herbicides is not advised due to soil health hazards and environmental pollution in such a fragile ecosystem. In ridge and furrow, better WSE of 36.0% obtained as compared to the flat bed. Similarly, 6 row arrangements had 21.5% and 3 rows had 11.2% better weed suppression than normal planting. In contrarily, placement of groundnut haulm mulch had 5.1% lesser weed suppression than no mulch plots.

Yield attributes and yield

Planting method, row arrangement and mulching influenced the yield attributes and yield of toria mustard (**Table 3**). Between the planting methods, ridges and furrow had 5% more branches/ plant, 11% higher siliqua/plants and 8% more seeds/ plant, these help in harvesting higher seed yield of toria mustard by 11% (1218.3 kg/ha) over flat bed planting (1.097.8 kg/ha). A similar finding was also corroborated by Choudhary *et al.* (2013) in maize. Among row arrangements, at 3 and 6 row arrangements each has 8% more branches/plant, whereas, 6 rows have 6% higher siliqua and 4% more seeds/plants, while 3 rows have obtained 4% higher siliqua over normal row planting (30 × 10 cm). Better yield attributes in 6 row arrangements resulting in

Table 2. Effect of planting methods, row arrangement and mulching on weed density, weed dry biomass and weed suppression efficiency at 60 DAS in toria mustard

Treatment	Weed density (no./m^2)				Weed dry biomass (g/m^2)				WSE (%)
	BLW	Grasses	Sedge	Total	BLW	Grasses	Sedge	Total	
Planting method									
Flat bed	13.0(170.1)	5.7(32.6)	3.7(13.3)	14.6(216.0)	6.5(42.9)	3.7(13.5)	2.7(7.0)	8.0(63.4)	19.3
Raised bed	10.5(111.2)	4.3(18.2)	3.1(9.4)	11.7(138.8)	5.0(24.3)	2.6(6.5)	2.2(4.3)	5.9(35.1)	55.3
LSD (p=0.05)	0.51	0.18	0.32	0.48	0.25	0.12	0.22	0.24	
Row arrangement									
Normal	12.4(158.0)	5.4(29.5)	3.5(12.2)	14.0(199.7)	6.2(39.5)	3.5(12.1)	2.6(6.3)	7.5(57.9)	26.4
3 rows	11.6(138.2)	5.0(25.2)	3.5(11.8)	13.1(175.2)	5.7(33.1)	3.2(10.0)	2.5(5.9)	7.0(49.0)	37.6
6 rows	11.1(125.7)	4.6(21.4)	3.2(10.2)	12.5(157.3)	5.3(28.2)	2.8(7.9)	2.3(4.8)	6.4(40.9)	47.8
LSD(p=0.05)	0.62	0.22	NS	0.58	0.31	0.14	NS	0.29	
Mulching									
No mulch	10.6(113.1)	5.5(30.4)	3.2(10.0)	12.3(153.5)	5.4(29.1)	3.5(12.6)	2.4(5.4)	6.8(47.1)	39.8
Mulch at 4 t/ha	12.9(168.2)	4.5(20.4)	3.6(12.8)	14.1(201.3)	6.1(38.0)	2.8(7.4)	2.5(6.0)	7.1(51.4)	34.7
LSD (p=0.05)	0.51	0.18	0.32	0.48	0.25	0.12	NS	0.24	

BLW= Broad-leaf weeds; WSE= Weed smothering efficiency; *Figures in parentheses are original means and data are subjected to square root transformation

Table 3. Effect of planting methods, row arrangement and mulching on yield attributes and yield of toria

Treatment	Branches /plant	Siliqua /plant	Seeds /siliqua	Seed yield (kg/ha)	Stover yield (t/ha)
Planting method					
Flat bed	4.0	140	8.1	1.10	2.27
Raised bed	4.2	155	8.7	1.22	2.52
LSD (p=0.05)	NS	2.8	0.3	0.02	0.04
Row arrangement					
Normal	3.9	143	8.3	1.11	2.28
3 rows	4.2	148	8.3	1.16	2.41
6 rows	4.2	151	8.6	1.20	2.50
LSD (p=0.05)	NS	3.5	NS	0.03	0.06
Mulching					
No mulch	3.8	138	8.1	1.08	2.23
Mulch at 4 t/ha	4.4	157	8.7	1.23	2.56
LSD (p=0.05)	0.23	2.8	0.3	0.02	0.05

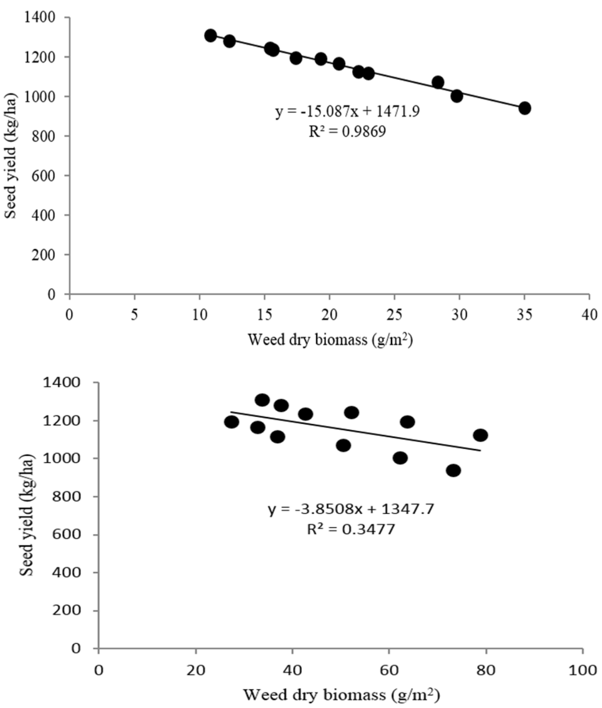

Figure 1. Relationship between seed yield and a) weed dry biomass at 30 DAS, and b) weed dry biomass at 60 DAS in toria

higher seed yield of 9% (1205.4 kg/ha) and stover yield by 10% (2999.1 kg/ha) and in 3 rows it was 5 and 6% (1162.8 and 2407.8 kg/ha, respectively) over normal row planting. Between mulch, placement of groundnut haulm mulch at 4 t/ha recorded better yield attributes *i.e.* 15% more branches/plant, 14% higher siliqua/plant and 8% more seeds/siliqua over no mulch resulted in harvesting higher seed and stover yield by 14 and 15% (1232.8 and 2562.4 kg/ha, respectively) over no mulch. The findings are conformity with the earlier findings of Choudhary (2016) in maize-frenchbean-toria cropping system. The seed yield of toria and weed dry biomass at 30 DAS has found strong negative linear relationship with coefficient of determination of 0.98 (**Figure 1a**). Whereas, with progress of crop duration at 60 DAS, there was negative correlation but the effect was non-significant (**Figure 1b**).

It can be concluded that in the fragile ecosystem of North-Eastern Himalayan Region, sowing of toria mustard in ridges and furrow with 6 or 3 row arrangements and mulching with groundnut haulm would be sustainable options for effective weed suppression and higher productivity.

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Sowing date and weed management effects on weeds, nutrient uptake and productivity of summer greengram

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ABSTRACT

A field experiment was conducted during the summer seasons of 2016 and 2017 at Banka, (Bihar) to evaluate the effect of sowing dates and weed management on weeds and productivity of summer greengram (*Vigna radiata* L.). The experiment was laid out in a split plot design replicated thrice. Eleven weed species, *viz. Cynodon dactylon*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Panicum repens*, *Cyperus rotundus*, *Amaranthus viridis*, *Celosia argentea*, *Commelina benghalensis*, *Digera arvensis*, *Euphorbia hirta* and *Trichodesma indicum* infested the greengram.Two hands weedings 20 and 40 days after sowing (DAS) recorded the lowest weed density and biomass which was significantly superior over rest of the weed management treatment. Pendimethalin (1000 g/ha) 2 DAS *fb* one hand weeding at 20 DAS gave significantly higher plant height, pods/plant, seeds/pod and seed index, higher seed yield, maximum net returns and B:C ratio and was found at par with two hands weeding at 20 and 40 DAS. Pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 20 DAS recorded the highest nutrient uptake N, P and K and was at par with of pendimethalin (1000 g/ha) 2 DAS during both years of experimentation.

Legume crops play a vital role as they provide food, feed and also maintains the soil environment by biological nitrogen fixation (Singh *et al.* 1970). Sowing time is one of the most important non-monetary agronomic factors for realizing the yield potential of improved varieties. Sowing of the crop at optimum time therefore, plays a key role in obtaining the high seed yields (Rathore *et al.* 2010). Among several factors responsible for low yields of pulse crops in India, weed infestation is considered as one of the major factors. Greengram often suffers severe weed competition especially during early growth phases. Being a short duration and initially slow growing, greengram is heavily infested with narrow and broad-leaved weeds and sedges which compete with crops, resulting in yield reduction to the tune of 30-79% (Lawn 1995, Shuaib 2001, Dungarwal *et al.* 2003). Therefore, removal of weeds at appropriate time using a suitable method is essential to obtain high yield of greengram. Delayed removal of weeds is not as effective in controlling weeds and obtaining higher yields as the timely removal of weeds. Thus, the present study was conducted with an objective to study the effect of sowing dates and weed management treatments on weeds and summer greengram yield and nutrient uptake.

A field experiment was conducted during summer seasons of 2016 and 2017 at farmer's field ($24^{0}30'$N latitude and $86^{0}30'$E latitude at an altitude of 79 m from the mean sea level) in Banka District of Bihar as an On Farm Trial to evaluate the effect of different sowing dates and weed management treatments on weed density and biomass, production and nutrient uptake of summer greengram. The soil of experimental site was sandy-clay-loam in texture with neutral pH (7.23), low in organic C (0.46%) and available N (193.5 kg/ha), and medium in available P (17.1 kg/ha) and K (213.3 kg/ha). The field experiment consisted four sowing dates in main plot, (15 March, 25 March, 5 April and 15 April) and four weed management treatments in sub plot, (weedy check, two hands weeding at 20 and 40 DAS, pendimethalin 1.0 kg/ha pre-emergence *fb* 1 hand weeding at 20 DAS and pendimethalin 1.0 kg/ha pre-emergence alone was conducted with the greengram cultivar '*HUM-16*'. The land was prepared by giving two ploughing each followed by planking with the help of a tractor-drawn cultivator. The sowing of greengram was done behind the plough after preparation of field at 30 x 10 cm apart. An uniform fertilizer dose of 20 and 40 kg N and P_2O_5/ha, respectively in the form of urea and diammonium phosphate was applied to each experimental unit. Full dose of nitrogen and phosphorus was applied at the time of sowing. Treatment-wise pre-emergence herbicide was applied at 2 day after sowing (DAS) by knap-sack sprayer fitted with flat-fan nozzle using water volume of 300 L/ha. Weed and crop samples were collected from each individual plot for studying various crop and weed characters. Weed samples were collected by placing a quadrat (0.5 x 0.5 m) randomly at two places in each plot. The data on density and biomass of total weeds were subjected to square root transformation before statistical analysis to obtain homogeneity of variances. The data on density and biomass of total weeds were taken at 20 and 40 DAS and grain yield (t/ha) was recorded at the time of harvest. The dried samples were ground in willey mill. The powdered material collected was used for chemical analysis of N, P and K content as suggested by Subbiah and Asija (1973) for N, Olsen *et al*. (1954) for P and Jackson (1973) for K. Total N, P and K uptake was calculated for each treatment separately by multiplying per cent content in the tissue with their respective dry matter values and expressed as kg/ha.

Density and biomass of weeds

The crop field was infested with complex weed flora comprising grasses, sedges and broad-leaved weeds. The predominant weeds were the predominant weeds were *Cynodon dactylon* (8.30/m^2), *Dactyloctenium aegyptium* (7.68/m^2), *Digitaria sanguinalis* (7.01/m^2) and *Panicum repens* (6.24/m^2) among the grasses. *Cyperus rotundus* (5.38/m^2) was the dominant sedge. *Amaranthus viridis* (5.03v), *Celosia argentea* (4.86/m^2), *Commelina benghalensis* (4.33/m^2), *Digera arvensis* (3.92/m^2), *Euphorbia hirta* (3.43/m^2) and *Trichodesma indicum* (3.03v) were the major broad-leaved weeds.

The maximum weed density and biomass were recorded under weedy check as compared to all weed management treatments. Pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 20 DAS was found to be the most effective with significantly lower weed density and biomass at 20 and 40 DAS than pendimethalin (1000 g/ha) 2 DAS and weedy check (**Table 1**).The better performance of combination of chemical and physical method might be due to synergistic effect between the two methods are reducing the weed population as well as dry matter. Raman and Krishnamurthy (2005) have also reported pre-emergence application of pendimethalin at 0.75 kg/ha+ 1HW at 30 DAS as most effective treatment of weed control.

Weed control efficiency

The weed control efficiency at 20 and 40 DAS was more with 15 march sowing (**Table 1**). The maximum weed control efficiency was recorded under pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand

Table 1. Effect of different sowing dates and weed management treatments on weed density, biomass and weed control efficiency in summer greengram.

Treatment	Weed density (no./ m^2)				Weed biomass (g/m^2)				WCE (%)			
	20 DAS		40 DAS		20 DAS		40 DAS		20 DAS		40 DAS	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Sowing dates												
15 March	7.88 (63.1)	7.80 (61.8)	10.98 (121.6)	10.91 (120.0)	6.06 (37.7)	6.54 (43.8)	13.00 (170.0)	12.69 (162.0)	70.9	65.7	55.7	55.3
25 March	7.97 (64.5)	7.89 (63.2)	11.37 (130.3)	10.99 (121.8)	6.64 (45.1)	6.64 (45.1)	13.01 (170.3)	12.99 (169.7)	65.2	64.7	55.6	53.1
05 April	8.07 (66.1)	8.01 (65.2)	11.69 (137.6)	11.51 (133.5)	6.98 (49.7)	7.01 (49.1)	13.11 (172.9)	13.08 (172.1)	61.6	61.5	54.9	52.5
15 April	8.55 (74.1)	8.40 (71.6)	11.88 (142.1)	11.80 (140.2)	7.99 (64.8)	7.81 (62.0)	13.61 (186.2)	13.66 (187.6)	50.0	51.4	51.4	48.2
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	-	-	-	-
Weed management												
Pendimethalin (1000 g/ha) 2 DAS *fb* 1 HW at 20 DAS	6.11 (38.3)	6.02 (37.2)	8.33 (70.4)	8.11 (66.8)	5.90 (35.8)	5.83 (35.0)	9.11 (84.0)	9.02 (82.4)	72.4	72.6	78.1	77.3
Pendimethalin (1000 g/ha) 2 DAS	8.87 (79.7)	8.71 (76.9)	12.56 (158.7)	12.47 (156.5)	7.99 (64.8)	7.92 (63.7)	13.32 (206.1)	13.24 (176.3)	5.0	50.7	46.3	51.3
Two hand weeding 20 and 40 DAS	3.40 (12.6)	3.36 (12.3)	5.47 (30.9)	5.39 (30.0)	2.70 (8.3)	2.28 (6.2)	6.19 (39.3)	6.11 (38.3)	93.6	95.1	89.7	89.4
Weedy check	12.97 (169.2)	12.81 (165.9)	18.90 (358.2)	18.62 (347.7)	11.34 (129.6)	11.30 (127.7)	19.56 (383.6)	19.01 (362.4)	0	0	0	0
LSD (p=0.05)	2.21	2.20	2.61	2.58	2.06	2.05	2.91	2.90	-	-	-	-

*Data subjected to square root ($\sqrt{x+1}$) transformation and figures in parentheses are original value, DAS - Days after sowing; *fb*- followed by, WCE- Weed coefficient efficiency; NS- Non significant; HW=Hand weeding

weeding at 20 DAS and two hand weeding 20 and 40 DAS during both years of experimentation. These above are in accordance with those of Chand *et al.* (2003) and Gangwar *et al.* (2013).

Effect on crop

The maximum plant height, pods/plant, seeds/ pod and seed index were recorded with sowing of greengram on 15th March **(Table 2)** and was found at par with sowing of greengram on 25th March during both year of experimentation. Pendimethalin (1000 g/ ha) 2 DAS *fb* 1 hand weeding at 20 DAS gave significantly higher plant height, pods/plant, seeds/ pod and seed index over weedy check, and was found at par with two hand weeding at 20 and 40 DAS during both years of experimentation. The higher yield was obtained in timely sowing, due to owing favorable temperature and humidity during their growth period and nodulation formation stage resulting in better growth. Both the years' data indicated significant decrease in seed yield of summer greengram with the delay in sowing period. The maximum seed yield was recorded under sowing of greengram on 15th March and was found at par with sowing of greengram on 25th March. The application of pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 20 DAS gave significantly higher seed yield and was found at par with two hand weeding 20 and 40 DAS. This was in agreement with Malik *et al.* (2000), Chhodavadia *et al.* (2013).

Economics

The net returns and B:C ratio were the highest with the sowing of greengram on 15th March than sowing of greengram on 5th and 15th April. It was at par with sowing of greengram on 25th March **(Table 3)**. The application of pendimethalin (1000 g/ ha) 2 DAS *fb* 1 hand weeding at 20 DAS gave significantly higher net return and B: C ratio over weedy check and it was on par with two hands weeding 20 and 20 DAS. These observations are in accordance with those of others (Srinivasan *et al.* 1992, Chand *et al.* 2003 and Gangwar *et al.* 2013).

Table 2. Effect of different sowing dates and weed management treatments on yield of summer greengram

Treatment	Yield attribute								Seed yield (kg/ha)	
	Plant height (cm)		Pods/plant		Seeds/ pod		100-seed weight (g)			
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Sowing date										
15 March	49.10	51.70	12.17	12.21	9.91	10.04	3.98	4.01	1251	1290
25 March	46.15	48.07	11.36	11.43	9.33	9.69	3.96	4.00	1156	1199
05 April	40.02	42.10	9.04	9.18	6.85	7.09	3.77	3.80	918	962
15 April	35.61	37.95	7.99	8.07	6.55	6.74	3.68	3.72	801	841
LSD (p=0.05)	5.08	5.43	2.38	2.42	1.81	1.77	0.13	0.15	149	155
Weed management										
Pendimethalin (1.0 kg/ha) 2 DAS *fb* 1 HW at 20 DAS	44.80	44.97	11.72	11.84	9.99	10.03	4.02	4.04	953	966
Pendimethalin (1.0 kg/ha) 2 DAS	40.49	40.54	9.46	9.68	9.03	9.04	3.89	3.90	821	829
Two hand weeding 20 and 40 DAS	47.41	47.60	12.25	12.63	10.76	10.81	4.07	4.08	1018	1044
Weedy check	33.45	34.04	6.04	06.14	5.17	5.42	3.15	3.16	637	652
LSD (p=0.05)	4.30	4.31	1.90	2.05	0.81	0.86	0.11	0.12	131	134

Table 3. Effect of different sowing dates and weed management treatments on economics and nutrient uptake of summer greengram

Treatment	Economics				Nutrient uptake (kg/ha)					
	Net return (x10^3 `/ha)		B:C ratio		Nitrogen		Phosphorus		Potassium	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Sowing date										
15 March	31.22	33.74	1.76	1.94	40.01	40.72	6.81	6.95	42.83	43.73
25 March	27.72	29.77	1.59	1.78	33.97	34.89	6.09	6.11	38.51	39.33
05 April	20.65	23.31	1.12	1.29	30.46	31.04	5.27	5.37	31.79	32.38
15 April	13.59	15.83	0.86	0.98	24.02	24.92	4.51	4.61	26.77	27.31
LSD (p=0.05)	5.48	5.73	0.28	0.35	2.98	3.01	0.69	0.72	3.57	3.66
Weed management										
Pendimethalin (1.0 kg/ha) 2 DAS *fb* 1 HW at 20 DAS	20.53	23.98	1.21	1.38	35.10	35.18	5.61	5.65	37.64	37.92
Pendimethalin (1.0 kg/ha) 2 DAS	19.65	22.77	1.10	1.20	32.03	32.08	4.76	4.87	32.35	32.82
Two hands weeding 20 and 40 DAS	21.03	23.63	1.03	1.11	39.12	39.44	6.96	7.00	44.22	42.99
Weedy check	12.34	12.90	0.75	0.72	15.02	15.13	2.42	2.45	16.38	16.72
LSD (p=0.05)	5.02	5.12	0.34	0.36	4.00	4.05	0.91	0.93	5.19	5.24

DAS = Days after seeding; *fb* = followed by; HW = Hand weeding

Nutrient uptake

Nutrient (N, P and K) uptake was more in 15th March sowing and was significantly superior than sowing on 25th March, 5th April and 15th April **(Table 3)**.The application of pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 20 DAS recorded the highest nutrient uptake N, P and K and was at par with of pendimethalin (1000 g/ha) 2 DAS during both the years of experimentation. The results are in accordance with finding of Choudhary *et al.* (2012) in blackgram. Kaur *et al*. (2010) reported the maximum amount of N uptake with hoeing and weeding twice, the P uptake with two hoeings by wheel toe and K uptake with pendimethalin 0.75 kg/ ha.

It may be concluded that, the sowing of greengram from 15th March resulted significantly higher seed yield and monetary return. Application of pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 20 DAS was found effective in managing weeds in summer greengram.

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Weed management in groundnut with new herbicide molecules

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ABSTRACT

A field experiment was conducted to study the effect of different high efficiency herbicides as pre- and post-emergence application on weed growth, yield and economics of groundnut at Tirupati campus of Acharya N.G. Ranga Agricultural University during *Rabi*, 2018. Among all the weed management practices, the broad-spectrum weed control with higher pod yield and benefit-cost ratio were obtained with pre-emergence application of diclosulam 20 g/ha followed by hand weeding at 40 DAS and next best option could be the pre-emergence application of diclosulam 20 g/ha followed by cycloxydim 100 g/ha at 20 DAS in sandy loam soils.

Weed infestation is an important limiting factor in achieving potential productivity of groundnut (*Arachis hypogaea* L.), especially in bunch type of varieties with poor competitive ability. Yield loss due to heavy weed infestation in groundnut ranged from 13-80 % in India (Ghosh *et al.* 2000). Unlike other crops, weeds interfere with pegging, pod development and harvesting of groundnut during different stages of crop growth, besides competing for growth resources. Use of pre- and post-emergence herbicides offers an alternative viable option for effective and timely control of weeds in groundnut. But, each herbicide has its own spectrum of weed control. The timing of herbicide application also has much concern on weed control efficiency. At present, pendimethalin 1000 g/ha as pre-emergence is being used most commonly for the control of weeds in groundnut, but it is less effective on some of the broad-leaved weeds and perennial sedge *Cyperus rotundus*. Post-emergence application of imazethapyr 75 g/ha is recommended for control of weeds in groundnut, but the choice of succeeding crops is limited because imazethapyr persists in soil and plant for longer time with a half-life period of 33 months and is not effective against grasses (Sondhia *et al.* 2015). Further, pre-emergence herbicides have been proved remarkably effective upto 20-25 DAS, but late coming weeds interfere with pegging, pod development and harvesting. In this context, there is need to evaluate suitable pre-and post-emergence herbicides to control all the categories of weeds including perennial sedge, *Cyperus rotundus* in *Rabi* groundnut.

A field experiment was conducted during *Rabi* 2018-19 in sandy loam soil of dryland farm of S.V. Agricultural College, Tirupati, Andhra Pradesh. The soil was low in available nitrogen and phosphorous, medium in potassium and low in organic carbon content. Healthy and sound groundnut kernel of test variety '*Kadiri-6*' were sown on 13 December, 2018 at spacing of 22.5 x 10 cm by using seed rate of 150 kg/ha. The crop was harvested on 29 March 2019. Eleven weed management practices consisted of pre-emergence (PE) application of diclosulam 20 g/ha alone or supplemented with HW at 20 DAS or post-emergence (PoE) application of haloxyfop-p-ethyl 135 g/ha at 20 DAS or cycloxydim 100 g/ha at 20 DAS, PE application of pendimethalin 725 g/ha alone or supplemented with HW at 40 DAS or post-emergence application of haloxyfop-p-ethyl 135 g/ha at 20 DAS or cycloxydim 100 g/ha at 20 DAS, PE application of pendimethalin 1000 g/ha alone, two hand weeding at 20 and 40 DAS and unweeded check. The experiment was laid out in randomized block design with three replications. Pre-and post-emergence herbicides were applied at one and 20 DAS by using battery operated knapsack sprayer fitted with flat-fan nozzle with spray fluid of 500 L/ha. The crop was supplied with recommended fertilizer dose of fertilizers with 20 kg N, 40 kg P_2O_5 and 50 kg K_2O/ha through urea, single super phosphate and muriate of potash, respectively to all the plots as basal. Top dressing of 10kg of N was applied in form of urea at 25 DAS. The rest of the package of practices was adopted as per Acharya N. G. Ranga Agricultural University. The unweeded check plots were allowed to remain infested with weeds till harvesting of the crop. Density and dry weight of weeds were recorded at harvest and transformed to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution. The number of filled pods/plant, pod and haulm yields of groundnut were recorded at harvest.

Table 1. Effect of different pre-and post-emergence herbicides on weed growth, yield and economics of *Rabi* groundnut

Treatment	Dose (g/ha)	Time of application (DAS)	Weed density (no./m^2)	Weed dry weight (g/m^2)	Plant height (cm)	Pod yield (t/ha)	Haulm yield (t/ha)	Net returns ($x10^3$ `/ha)	B:C ratio
Pendimethalin (CS)	725	1	7.16(50.3)	6.64 (43.6)	26.68	1.55	2.57	34.62	2.04
Diclosulam	20	1	4.33(18.0)	3.36(10.3)	25.41	1.76	2.80	44.03	2.35
Pendimethalin *fb* hand weeding	725	1 *fb* 40	5.91(34.0)	5.53(29.7)	27.64	1.60	2.61	34.40	1.97
Diclosulam *fb* hand weeding	20	1 *fb* 40	2.99(8.0)	2.57(5.6)	25.85	2.10	3.05	56.48	2.62
Pendimethalin *fb* haloxyfop-p-ethyl	725 *fb*135	1 *fb* 20	7.50(55.3)	6.83(45.7)	27.87	1.65	2.68	36.22	2.02
Diclosulam *fb* haloxyfop-p-ethyl	20 *fb*135	1 *fb* 20	4.19(16.7)	3.13(8.9)	25.93	1.86	2.85	46.06	2.32
Pendimethalin *fb* cycloxydim	725 *fb*100	1 *fb* 20	7.04(48.7)	6.54(41.9)	28.45	1.70	2.73	39.49	2.14
Diclosulam *fb* cycloxydim	20 *fb*100	1 *fb* 20	3.86(14.0)	2.82(7.0)	26.59	1.93	2.91	49.92	2.47
Pendimethalin (EC)	1000	1	8.99(80.0)	6.72(44.6)	27.29	1.61	2.62	37.24	2.12
Hand weeding	-	20 *fb* 40	5.39(28.3)	4.71(21.6)	29.53	1.80	2.81	41.13	2.10
Unweeded check (control)			15.0(224.3)	10.4(108.7)	20.73	1.07	1.95	15.63	1.50
LSD (p=0.05)			0.64	0.69	3.81	0.24	0.31	5.42	0.14

The figures in parentheses are original values; CS= Capsulated suspension, EC= Emulsifiable concentrate; *fb*= followed by

The predominant weed species observed in the experimental field were *Cyperus rotundus*, *Boerhavia erecta*, *Commelina bengalensis*, *Celosia argentea*, *Cleome viscosa*, *Dactyloctenium aegyptium*, *Phyllanthus niruri* and *Trichodesma indicum.* All the weed management practices significantly influenced the weed growth and yield of *Rabi* groundnut (**Table 1**). The lowest density and dry weight of total weeds were recorded with pre-emergence application of diclosulam 20 g/ha supplemented with HW at 40 DAS, which was significantly superior than rest of treatments with respect to weed density and comparable with pre-emergence application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha with respect to weed dry weight. Both the weed management practices were significantly superior in reducing density and dry weight of total weeds than two hand weedings at 20 and 40 DAS. Pre-emergence application of diclosulam 20 g/ha found to be very effective in controlling all the categories of weeds compared to pre-emergence application of both the formulations (CS and EC) of pendimethalin including predominant perennial sedge, *Cyperus rotundus* in the experimental field. Price and Wilcut (2002) also stated that diclosulam 27 g/ha found to be very effective in controlling yellow nutsedge upto 65-100 per cent when it was applied alone or in combination with dimethenamide. Diclosulam inhibits the acetolactate synthase, a key enzyme responsible for biosynthesis of branched chain amino acids, which are necessary for cell division at meristematic region of target plants.

Hand weeding twice at 20 and 40 DAS produced the tallest plants due to maintenance of weed free environment and better soil physical condition which might have enhanced the inter nodal length and it was at par with sequential application of pendimethalin *fb* cycloxydim 100 g/ha at 20 DAS. The highest pod yield (2.10 t/ha) and haulm yield (3.05 t/ha) of groundnut was obtained with pre-emergence application of diclosulam 20 g/ha supplemented with hand weeding at 40 DAS, which was closely followed by sequential application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha. Application of diclosulam as pre-emergence and cycloxydim as post-emergence controlled all the categories of weeds, which in turn increased the yield components and yield of groundnut. Similar results were also reported earlier by Grey *et al.* (2001). The reduction in pod and haulm yield of groundnut in unweeded check plots of *Rabi* groundnut was 48.8 and 36.1%, respectively compared to the best weed management practice *i.e* pre-emergence application of diclosulam *fb* hand weeding. These results are in conformity with those of Clewis and Wilcut (2004). The highest net returns and benefit-cost ratio were obtained with pre-emergence application of diclosulam *fb* hand weeding at 40 DAS, which were significantly higher than with pre-emergence application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha at 20 DAS due to increased yield. The highest weed density and dry weight with lower pod and haulm yield were registered with unweeded check due to heavy weed competition.

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Scheduling weed management practices for improving weed control efficiency and bulb yield in onion

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ABSTRACT

An experiment was conducted under All India Network Research Project on Onion and Garlic, operating at the College of Horticulture, Orissa University of Agriculture and Technology, Sambalpur, Odisha during *Rabi*, 2010-11 to compare the efficacy of different weed control methods in onion. The experiment was laid out in a randomized block design with eight combinations of weed management practices and replicated thrice. Results revealed that significantly highest marketable bulb yield (19.19 t/ha) and total bulb yield (22.80 t/ha) was obtained with a higher percentage 'A' grade bulb (34.04 %) and an average bulb weight (69.83 g) by the application of oxyfluorfen before planting + one hand weeding at 45 days after transplanting. The identical weed management practice recorded highest 66.09% of weed control efficiency along with the lowest number of monocot weeds (26.33/ m^2), minimum fresh weight of weeds (40.08 g/m^2) and minimum dry weight of weeds (14 g/m^2). Imposition of manual hand weeding at 45 DAT facilitates a weed-free situation to the crop. Hence, it was concluded that maximum bulb yield can be obtained with the application of oxyfluorfen before planting + one hand weeding at 45 DAT due to the influence of oxyfluorfen and one manual hand weeding on monocot weeds during the crop growth period.

Onion (*Allium cepa* L.) is an important export-oriented vegetable crop, valued for its distinctive flavor and spiciness. Being an indispensable ingredient of both vegetarian and non-vegetarian diets, its demand is getting increased as the only vegetable spices. India contributes 21.5% share in world onion production although it globally ranks ninth in terms of productivity (FAOSTAT 2019). The productivity of onion is reasonably low and remains almost static with negligible variation since a long period. Weed infestation is one of the vital limiting factors that cause comparatively more losses than those caused due to insect pests and diseases. Crop losses due to weeds vary from 30 to 95% in onion (Praksh *et al.* 2000, Rameshwar *et al.* 2001; Udit Kumar 2014).Weed seeds get dispersed to the field under dormant condition at the time of incorporation of farmyard manure during field preparation and unvaryingly nourished with the transplanted onion seedlings. Concurrently, the weeds compete with onion seedlings for nutrients, soil moisture, space and light. In fact, onion is a slow growing crop with a shallow root system and non-branching habit. Moreover, the cylindrical upright tapered leaves create a sparse foliage, making the crop unable to cover the soil surface for prevention of weed growth. Ultimately the crop facilitates the weed growth by encouraging favorable circumstances with sufficient sunlight, air coupled with regular irrigation and high fertilization. Very regrettable crop-weed competition has been reported in onion (Channapagoudar and Biradar 2007, Barla and Upasani 2019). Chemical weed control or use of herbicides is the only modern tool to manage the crop-weed competition. It is easy and convenient to use, apart from that, it reduces the cost of labour required for the hand weeding. However, like other agrochemicals, judicious application of herbicides is also essential to obtain maximum economic returns. The critical period of crop-weed competition ranges from 30 to 40 days after transplanting (DAT) in onion (Sathyapriya *et al.* 2017), and it may even go up to 50 DAT (Qasem 2005). An effective weed management practice during the critical crop growth stage is very essential to obtain an optimum economic yield. Keeping this in mind the present experiment was formulated to assess the efficacy herbicides solely and in combination with different weed control practices at different crop growth stages in onion.

A field experiment was conducted under All India Network Research Project on Onion and Garlic operating at the College of Horticulture, Orissa University of Agriculture and Technology, Chiplima, Sambalpur, Odisha during *Rabi*, 2010-11 in a randomized block design with three replications. There were eight treatments *viz.* oxyfluorfen 235 g/ha before planting and at 30 DAT, oxyfluorfen 235 g/ha before planting *fb* quizalofop-ethyl 87.5 g/ha at 30 DAT, oxyfluorfen 117.5 g/ha + quizalofop-ethyl 43.7 g/ha at the time of planting and at 30 DAT, pendimethalin 750 g/ha before planting and at 30 DAT, pendimethalin 750 g/ha before planting *fb* quizalofop-ethyl 87.5 g/ha at 30 DAT, pendimethalin 375 g/ha + quizalofop-ethyl 43.7 g/ha at the time of planting and at 30 DAT, oxyfluorfen 235 g/ha before planting *fb* one hand weeding at 45 DAT and weedy check. The soil of the experimental site was sandy loam soil having pH of 5.89; available NPK 151.25:15.78:178.75 kg/ha and low sulphur content (9.75 ppm). The climatic condition of this locality was warm/sub-humid with the temperature ranging from 9^{o}C to 44.2^{o}C. This research site was a weed prone area under Western Table Land Zone of Odisha with wide diversities of monocot and dicot weeds.

Onion seedlings (*cv.* Agrifound Dark Red) of eight weeks' old were transplanted in the main field at a spacing of 15 x 10 cm in individual plot size of 10 m^2. All recommended packages of practices other than weed management were adapted uniformly to all the treatments to raise a good crop. Data on different vegetative growth parameters (plant height and number of leaves) were recorded at 75 DAT, where as yield parameters (average bulb weight, marketable bulb yield, and total bulb yield) were recorded at harvest. Weed parameters (number of weeds/m^2, fresh and dry weight of weeds/m^2) were recorded at 90 DAT. Weeds were counted from an area of 1 m^2 for each treatment, and categorized into monocots and dicots. Fresh weights of weeds (g/m^2) were recorded immediately after weeding at 90DAT, whereas dry weights of weeds (g/m^2) were recorded after complete hot air oven drying at 80^0 C for 48 hrs.

Weed control efficiency (WCE) was calculated as per the following formula (Mani *et al.* 1973):

$$WCE\ \% = \frac{WDc - WDt}{WDc} X100$$

where,

WCE: Weed control efficiency (%),

WDc: Dry weight of weeds in weedy check plot, and

WDt: Dry weight of weeds in treated plot.

The observed data were subjected to statistical analysis (Sukhatme and Amble 1995).

The results in **Table 1** revealed a significant variation in vegetative growth of onion plants due to treatments. Highest 56.67 cm of plant height was observed under combined spray of pendimethalin 375 g/ha + quizalofop-ethyl 43.7 g/ha at the time of planting and at 30 DAT, which was *at par* with the application of oxyfluorfen before planting along with one hand weeding at 45 DAT (56.39 cm). Maximum number of leaves per plant (15.37) was recorded with the application of oxyfluorfen 235 g/ha before planting *fb* quizalofop-ethyl 87.5 g/ha at 30 DAT which was also at par with the application of oxyfluorfen + one hand weeding. This might be due to considerable suppression of weeds throughout the cropping period. Application of Oxyfluorfen 235 g/ha before planting was reported as a pre-emergence herbicide that affects terrestrial plants. It strongly adsorbs to soil particles and comparatively motionless within the soil profile. It achieves toxicity in plants that restricts the emergence and growth of weeds in the early vegetative stage (Alister *et al.* 2009, Shaner 2014). Likewise, it allows a favorable condition to encourage appropriate vegetative growth of the crop like onion. An increase in number of leaves was proportionally related to the number of scale leaves in onion bulbs as well as the average weight of bulb. Imposition of manual hand weeding at 45DAT could facilitate a weed-free situation to the crop.

Application of oxyfluorfen before planting + one hand weeding (45 DAT) recorded the highest marketable bulb yield (19.19 t/ha) and total bulb yield (22.80 t/ha) as obtained under with a higher proportion 'A' grade bulb (34.04%) and an average bulb weight (69.83 g). This treatment was followed by the combined spray of pendimethalin 375 g/ha + quizalofop-ethyl 43.7 g/ha at the time of planting and at 30 DAT, registering the marketable bulb yield of 18.81 t/ha and total bulb yield of 216.77 q / ha with 27.39% 'A' grade bulb and an average bulb weight of 56.93 g (**Table 1**). Doubles and bolters in onion are very less consumer acceptability. Here in both of the above reveal weed management practices, the

Table 1. Effect of weed management practices on growth and yield of onion

Treatment	Plant height (cm)	Leaves/ plant	Average bulb weight (g)	Grading of bulb (%) A	B	C	% Double	% Bolters	Total bulb yield (t/ha)	Marketable bulb yield (t/ha)
Oxyfluorfen 235 g/ha before planting and at 30 DAT	54.10	14.43	52.73	20.23	31.49	29.32	1.97	1.88	15.25	12.38
Oxyfluorfen 235 g/ha before planting *fb* quizalofop-ethyl 87.5 g/ha at 30 DAT	53.65	15.37	57.07	25.63	32.53	27.79	1.85	2.15	20.49	17.62
Oxyfluorfen 117.5 g/ha + quizalofop-ethyl 43.7 g/ha at the time of planting and at 30 DAT	54.88	15.20	53.53	22.49	28.65	34.77	1.82	2.48	19.10	16.44
Pendimethalin750 g/ha before planting and at 30 DAT	49.51	14.77	56.00	22.15	31.62	16.48	2.55	3.01	15.09	10.60
Pendimethalin750 g/ha before planting *fb* quizalofop-ethyl 87.5 g/ha at 30 DAT	49.41	13.90	52.87	24.26	37.00	23.85	2.08	2.77	13.97	11.82
Pendimethalin 375 g/ha + quizalofop-ethyl 43.7 g/ha at the time of planting and at 30 DAT	56.67	14.57	56.93	27.39	32.38	27.00	1.93	1.80	21.68	18.81
Oxyfluorfen 235 g/ha before planting *fb* one hand weeding at 45 DAT	56.39	15.33	69.83	34.04	29.39	20.91	1.94	1.81	22.80	19.19
Weedy check	49.33	13.00	52.03	16.97	32.66	34.78	2.65	3.70	11.40	9.61
LSD (p=0.05)	5.51	1.47	10.05	8.90	NS	NS	0.48	1.15	4.12	3.44

NS: Not significant

Table 2. Effect of weed management practices on growth and yield of onion var. agrifound dark red

Treatment	MCW/ m^2	DCW/ m^2	FWMC (g/m^2)	FWDW (g/m^2)	DWMC (g/m^2)	DWDW (g/m^2)	WCE (%)	BCR
Oxyfluorfen 235 g/ha before planting and at 30 DAT	28.00	24.33	50.38	111.40	20.12	26.00	64.45	1.35
Oxyfluorfen 235 g/ha before planting *fb* quizalofop-ethyl 87.5 g/ha at 30 DAT	29.00	26.67	45.71	105.30	19.56	23.99	62.21	3.41
Oxyfluorfen 117.5 g/ha + quizalofop-ethyl 43.7 g/ha at the time of planting and at 30 DAT	35.00	23.00	83.39	123.50	18.30	27.45	60.63	2.83
Pendimethalin750 g/ha before planting and at 30 DAT	33.33	26.67	63.26	93.22	16.53	21.88	59.28	1.02
Pendimethalin750 g/ha before planting *fb* quizalofop-ethyl 87.5 g/ha at 30 DAT	31.33	16.00	82.31	63.45	16.55	14.66	67.90	1.14
Pendimethalin 375 g/ha + quizalofop-ethyl 43.7 g/ha at the time of planting and at 30 DAT	29.00	22.67	54.29	79.22	15.44	17.98	64.94	2.97
Oxyfluorfen 235 g/ha before planting *fb* one hand weeding at 45 DAT	26.33	23.67	40.08	106.22	14.00	23.67	66.09	2.64
Weedy check	79.67	67.67	115.40	163.40	30.11	36.98	0	
LSD (p=0.05)	3.75	3.39	14.67	11.13	5.11	6.36	3.61	-

MCW: No. of monocot weeds/m^2, DCW: No of dicot weeds/m^2, FWMC: Fresh weight of monocot weeds (g/m^2), FWDC: Fresh weight of dicot weeds (g/m^2), DWMC: Dry weight of monocot weeds (g/m^2), DWDW: Dry weight of dicot weeds (g/m^2), WCE: Weed control efficiency, BCR: Benefit-cost ratio

percentage of doubles and bolters are comparatively less which supports to the achieve the higher marketable bulb yield in onion.

There was a significant variation in the number of monocot and dicot weeds along with WCE among different weed management practices. Application of oxyfluorfen + one hand weeding recorded the lowest number of monocot weeds (26.33/ m^2), fresh weight of weeds (40.08 g/m^2) and dry weight of weeds (14 g/m^2). It was followed by pendimethalin + quizalofop-ethyl, registering these values at 16.00 nos. 63.45 and 14.66 g/m^2, respectively.

Results in **Table 2** revealed that both the treatments with the application of pendimethalin 750 g/ha before planting *fb* quizalofop-ethyl 87.5 g/ha at 30 DAT and oxyfluorfen 235 g/ha before planting *fb* one hand weeding at 45 DAT had a significant impact on weed suppression. Pendimethalin in integration with quizalofop-ethyl could suppress the dicot weed population, whereas oxyfluorfen along with one hand weeding suppressed the monocot population.

The crop field was dominated more with the monocot weeds. Most of the weeds were found to be kept under control with the influence of oxyfluorfen + one hand weeding during the crop growth period, leading to the production of the highest bulb yield in onion. An optimum WCE of 67.90% was observed with the application of pendimethalin (before planting) + quizalofop-ethyl (30 DAT), and was followed by oxyfluorfen (before planting) + one hand weeding (45 DAT) with WCE of 66.09%.

An optimum benefit-cost ratio of 3.41 was recorded with the application of oxyfluorfen (before planting) + quizalofop-ethyl (30 DAT). Maximum bulb yield was obtained with the application of oxyfluorfen (before planting) + one hand weeding (45 DAT). Thus, the application of oxyfluorfen 235 g/ha before planting along with one hand weeding at 45 DAT might be recommended for ensuring an appropriate weed management as well as achieving higher bulb yield in onion.

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Effect of mulching on weed management in areca nut in Andaman and Nicobar Islands

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ABSTRACT

A field investigation was conducted during October, 2018 - March, 2019 at Port Blair, to assess the impact of seven mulching practices [areca nut leaves (chopped and unchopped), husk, silver oak leaves, and black polythene] on areca nut along with weed free and weedy check treatments in randomised complete block design (RCBD) with five replications. Tree is taken as a replication. Results revealed that weed free treatment biomass (259.1 g/m^2) removed 82 kg (33.7 - 5.18 - 38.9 kg/ha of N-P-K) nutrients/ha. Black polythene mulching excluded the light supplies to weeds within 6 weeks time brought 100% weed control efficiency (WCE) and arrested the evapo-transpiration (ET) losses of weeds resulting in higher soil moisture content (SMC, %) in surface layer (0-10 cm). Organic mulches with lower WCE {77.63 (silver oak leaf mulch) - 92.93% (areca nut chopped leaf mulch)} than polythene mulching also contributed to higher SMC (0-10 cm). Mulching did not affect the SMC in deeper layer (10-30 cm). Weed free plots resulted in evaporation losses of moisture as that of ET losses of weedy check as evident form SMC. High cost of polythene mulches (` 41095/ha) when spread over its 5 year life span becomes cheaper than manual weeding (with recurring cost every year). However, due to every year organic mulching with farm generated residues soil organic matter may build up and thus enhances the water retention capacities and their ecological safety merits adoption. Soil (nutrient) and water conservation services of mulching in areca nut established in the study calls for its exploitation for weed management in islands.

Areca nut (*Areca catechu* L) or betel nut or Supari has a huge consumer base as evident from an estimated 600 million direct betel nut consumers globally and which further increases by 10–20% in the form of betel quid (paan, a preparation containing areca nut) users (Arora and Squier 2019). On account of the above global demand, areca nut cultivation was taken up by many farmers and in 2017 its area of cultivation has reached 0.956 million (m) ha with a production of 1.34 m tonnes (t) and out of this India has 46.6 and 54.0% share in the global area and production (FAOSTAT 2018). As per report of National Horticulture Board (NHB) during 2017-18, India produced 0.833 m t of areca nut from 0.497 m ha area (NHB, 2018). Andaman and Nicobar Islands (ANI) with 4625.5 ha area and 10,608 t areca nut production in 2016-17 accounts for 0.93 and 1.27% in countries area and production, respectively (DOES 2017). Tropical humid monsoonal climate (Am) of ANI with copious rainfall (300 cm), high humidity (66-93%) and isothermal (23-26^{0}C and 30-32.5^{0}C mean minimum and maximum) regime is highly congenial for areca nut cultivation. This is evident from the 36.3% (2.29 t/ha) higher average productivity than the country (1.68 t/ha). Rain fed areca nut cultivation of ANI across the topographies right from hill top to the sea coast faces several abiotic and biotic stresses and constraints and among them moisture and weeds are the most important. In sloppy lands, permanent sod cover is maintained between areca nut rows for soil conservation purpose while manipulating small area around the tree for input application (fertilizer / manure) and weeding as that of vine yards of USA (Bavougian and Read 2018).

Areca nut being a perennial crop, soil disturbance is not required as that of annual crops. Despite of high annual rainfall (300 cm in 140 days), areca nut do experience moisture stress during December-April months that gets further aggravated by the often unmanaged weeds growing along with the crop. Moisture stress limits crop nutrient uptake and they all together limits the productivity. Weed management is least emphasized in the Islands due to costly manpower, non-availability of machinery like power tillers, *etc*. The withdrawal of marketing permits to herbicides since October, 2018 in ANI has also closed the farmers use of glyphosate and paraquat for weed management. Further, herbicide use associated human, environmental problems and evolution of resistance in weed populations etc. calls for their limited or no use. In this context, mulching assumes to be a prominent technique for weed management. The annual leaf shred of 5–6 leaves (Bavappa and Murthy 1960) and fruit husk (0.8 kg/kg of fruit) of areca nut plantation generates 5-5.6 t/ha of farm wastes (Uma Maheswari *et al*. 2015) which could serve as mulch materials with associated soil, and water conservation functions (Jaganathan 2016) on account of reduced run off, evaporation losses (Ravi and Vivek 2001) improved soil structure and increased water infiltration (DeVetter *et al*. 2015) besides weed management (Gangaiah 2019). Based on assumption of 5 t/ha waste generation by areca nut crop, ANI has 23125 t of wastes during 2016-17. Areca nut husk is least utilized on account of lack of fibre extraction industries. while leaves are used as fuel to some extent. These residues available at the farm can be used as mulch. Further many ferns growing on the areca nut truck hampers the climbing of trees for manual harvest and oak leaf fern (*Drynaria quercifolia* (L.) J. Sm.) is one such widely growing flora in islands. Its biomass can also provide mulch material. However, residue mulching may enhance the pest (disease and insect) problems by serving as food (insect) or medium for harbouring disease inoculums. Partial ground coverage of organic mulches leading to light penetration to ground leads to growth of some weeds and thus is less effective. Moreover, clean cultivation is preferred by many farmers. Above reasons have paved the way for the use of plastic mulches. Though, residue mulching was practised since long time and plastic mulching is recommended in the islands in recent times, however, no scientific information was generated on their role in weed management and moisture and nutrient conservation. Keeping this in view, a field investigation was carried out to assess the utility of organic and inorganic (plastic) mulches on weed management and water and nutrient conservation in rain fed areca nut production system of Andaman and Nicobar Islands.

A field experiment was carried out during September, 2018 and March, 2019 at Garacharma Research Farm of ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman & Nicobar Islands located at 11^0 66’ N latitude and 92^0 75’ E longitude. The experimental site soil in top 30 cm depth was found to be neutral in reaction (6.7 pH) non-saline (ECe: 0.52 dS/m) and contained 259, 11.1 and 132 kg/ha of available nitrogen (N), phosphorus (P) and potassium (K). The soil moisture holding properties (0-30 cm) indicate a field capacity (FC) and permanent wilting point (PWP) moisture of 20 and 9%, respectively and soil has a bulk density of 1.45 g/cc. The study was conducted in fully grown up areca nut plantation of 20 years age (‘*Mangala*’ variety) in sole stands planted at 2.7 x 2.7 m spacing. The experiment was laid out in randomized complete block design (RCBD) with seven treatments that are replicated five times and single tree is taken as replication. Area encircling the areca nut tree trunk on 0.75 m radius (1.77 m^2 area) was used for imposition of treatment. Seven mulching treatments with un-chopped areca nut leaves, chopped areca nut leaves, areca nut fruit husk, oak fern (*Drynaria quercifolia*) leaves, black plastic mulch of 50 µ thickness along with no mulch-no weeding and no mulch - weed free through monthly manual hoeing with pick axe were evaluated. Treatments were imposed on 12th October, 2018. Ten areca nut leaves as unchopped and chopped (5 cm); areca nut fruit husk at 5 kg/tree; un chopped oak fern leaf at 3 kg/tree; black ploythene mulch (50 µ thick) were spread around the tree trunk. The weed flora of the experimental site was recorded in 1m^2 at 15 locations that were uniformly spread over experimental field. Plot wise weed count (grasses and broad-leaved weeds *i.e.,* BLW) was recorded from 0.25 m^2 quadrates at start of treatment imposition and converted to report on m^2 basis. From weed free treatment, weeds removed along with their roots every month were collected, separated into grasses and BLW. Root portion was separated and leftover above ground biomass was oven dried at 60^0 C for 48 hours so as to attain a constant weight and was expressed as dry weight g/m^2.

Soil moisture content (SMC) was determined up to 30 cm depth (0-10 and 10-30 cm) at 20 days interval during rain free period (15 January, 14 February and 16 March, 2019) by gravimetric method (Dastane 1972). Weed control efficiency (WCE) was worked out as per Ahlawat *et al.* (2005); WCE (%) = {Weed dry weight (g) in weedy check plot - weed dry weight in treatment plot /weed dry weight in weedy check plot} x 100. As weed count and dry weight data had zero values, the data was subjected to square root transformation ($\sqrt{x+0.5}$) prior to statistical analysis. Weed biomass was analysed for nutrient (NPK) concentration as per Dhyan Singh *et* *al.* (2005) and nutrient uptake (kg/ha) of grasses, BLW and their total was estimated as product of nutrient concentration (%) and weed dry matter (kg/ha)/100. For soil moisture depletion assessment, soil samples were drawn from 0.5 m away from areca nut tree bole at two depths (0-10 and 10-30 cm) and initial weight was recorded. The same samples were oven dried for 48 hours at 60^0C to attain constant weight and was recorded as dry weight. Soil moisture content (%) was calculated as: {initial soil weight (g) –oven dry soil weight/ oven dry soil weight} x 100. Cost of cultivation was worked out taking into consideration the input prices (material and men). For cost of cultivation calculation, a price of ` 26.6/palm was used for black polythene. No cost was considered for areca nut, silver oak fern leaves and husk. For areca nut leaf mulch (un-chopped) and silver oak fern leaf; areca nut chopped leaves and areca nut husk mulching, 5, 15 and 10 man days were used. For weed free plot, a labour cost of 30 man days was used. It was arrived as product of labour used /weeding (5 man days) and number of weedings (6) at monthly interval (October-March). More labour was used in first manual weeding (digging) that got reduced in subsequent weedings. Sum of labour used in 6 weedings was used in labour estimates. As areca nut is perennial crop, its yield is continuously formed and bunches are harvested. The bunches formed after imposition of treatments are yet to come to harvest (it takes 5-6 months for bunch formation-harvest), hence, yield data has not been not reported. A rainfall of 97.3 cm (October, 2018 – 20 March 2019) was received in 42 rainy days (**Figure 1**). The mean maximum and minimum temperature ranged from 29.8-31.7 and 19.7-22.2 ^{0}C during the study period with a mean relative humidity values of 70-92%. Mean monthly evaporation of Port Blair (1987-97) was 13.87 cm (11.61 cm in November and 16.45 cm in March). The analysis of variance for RCBD was done. The significance of treatment differences was compared by critical difference at

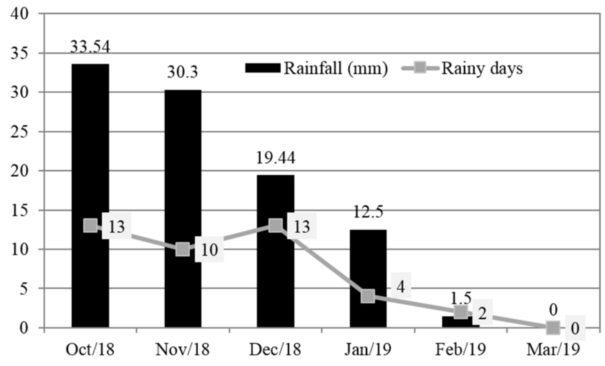

Figure 1. Monthly rainfall and rainy days at Shadipur, Port Blair weather station

5% level of significance (p=0.05) and statistical interpretation of treatments was done as per Gomez and Gomez (1984).

Experimental period have sufficient moisture up to first week of January, 2019. After, 8 January, there was meagre rainfall. During the rain free period (10 January- 12 March) recording of soil moisture was done for different treatments. Data showed that mean monthly rain fall was far behind the evaporation. Areca nut leaves fallen from tree were collected and 5 leaves were chopped in to small pieces (10 cm size) and oven dried at 60^0C for 72 hours and dry weight was recorded (g). The used leaves had an average weight of 197.5 g / leaf. Average weight of fruit husk collected from processing unit was 25 g.

Weed flora

Weed flora was recorded from no mulch (control) plot and the whole plantation area of the experiment. The weed flora of experimental field include mostly grasses, few dicots (shrubs and herbs) and 3 epiphytes (trailing on trunk). The grassy weeds were distributed as thick mat on ground and epiphytes on tree trunks; however, the BLW distribution was irregular in the experimental area and varied among treatments. *Ischaemum rugosum* Salisb.; *Eleusine indica* (L.) Gaertn.; *Oplismenus compositus* (L.) Beauv.; *Dinochloa andamanica* Kurz.; *Cynodon dactylon* (L.) Pers.; *Digitaria sanguinalis* L.(Scop.); *Themeda traindra* Forssk; *Setaria viridis* (L.) Beauv were the major grassy weed flora of the experimental site during the study period.

The dicot weeds: *Mucuna gigantea* (Willd.) DC.; *Ipomoea pes-caprae* (L.) R.Br.: *Mikania micrantha* H.B.K.; *Phyllanthus niruri* L.; *Tridax procumbense* L.; *Mimosa pudica; Ageratum conyzoides* (L.); Mill.; *Alysicarpus ovalifolius* (Schumach.) J. Leonard.; *Chromolaena odorata* (L.) King and Robins. *Clitoria ternatea* L.; *Convolvulus arvensis* L.; *Corchorus* sp; *Euphorbia geniculata* Orteg.; *Martynia annua* L.; *Cleome viscosa* L.; *Centrosema pubescens* Benth.; *Achyranthes aspera* L.; *Euphorbia hirta* L.; *Hyptis capitata* Jacq.; *Melastoma malabaricum* L. Three epiphytes: String of nickels or button orchid: *Dischidia nummalaria* R.Br*;* the Malayan urn vine *Dischidia major* (Vahl) Merr and*;* oak leaf fern: *Drynaria quercifolia* (L.) J. Sm. were recorded in the site uniformly.

Weed count, weed dry weight and weed control efficiency

Weed count recorded at the time of imposition of treatments (**Table 1**) indicate that on an average

Table 1. Weed count at start of treatments imposition and end of study under different mulches

Treatment	Weed count (no./m^2)					
	At start (12 October, 2018)			On 20 March, 2019		
	Grass	BLW	Total	Grass	BLW	Total
Areca nut leaf mulch	28.5	6.0	35.1	3.050 (8.8)	1.897 (3.1)	3.521 (11.9)
Areca nut chopped leaf mulch	29.7	6.5	36.2	2.302 (4.8)	1.673 (2.3)	2.757 (7.1)
Areca nut husk mulch	30.0	6.3	36.3	2.000 (3.5)	1.844 (2.9)	2.627 (6.4)
Silver oak leaf mulch	31.4	5.9	37.3	2.550 (6.0)	1.871 (3.0)	3.082 (9.0)
Black polythene mulch	30.7	6.7	37.4	0.707 (0.0)	0.707 (0.0)	0.707 (0.0)
Weedy check	30.8	6.4	37.2	5.648 (31.4)	2.646 (6.5)	6.197 (37.9)
Weed free check (no mulch)	31.0	7.0	38.0	0.707 (0.0)	0.707 (0.0)	0.707 (0.0)
LSD (p=0.05)	NS	NS	NS	0.384	0.151	0.250

*****Figures in parentheses are original values; Outside parenthesis data is $\sqrt{x+0.5}$ values, BLW: broad-leaved weeds

36.6 weeds (30.2 grasses and 6.4 BLW) were present in m^2 area. No significant differences in weed count among treatments showed their uniform distribution. In weed free treatment, the above ground dry weight of these weeds was recorded as 173.1 g/m^2 and of the total weed dry weight, 75.2% was of the grasses and the remaining 24.8% comprised of BLW. In the next 5 weedings (November, December, January, February and March), 25, 18, 12, 24, 7 g (86.0 g/m^2 total) of above ground weed biomass was produced. Weed biomass decreased substantially as weeds were removed along with their roots. Few weed roots left in soil and weed seed germinations have contributed to new weed biomass that varied from the highest of 25 g (November) to the lowest of 7 g (March). During February, there was higher biomass than January on account of rains (4-7 January) with that many new weeds have germinated. Weed count recorded on 12 March, 2019 (**Table 2**) showed 0 (zero) values in both weed free check and black polythene mulch treatments. Elimination of weeds by polythene mulching and their physical removal in weed free treatment were the reasons for the zero weed counts. Weedy check had the highest total weed count values (37.9). It showed that there was slight increase in weed count during the experimental period (6 months) over that recorded at the start of study in October. With drying of weeds and receipt of rains, few new weeds have germinated, hence slight increases in weed count was observed. Weed count differed among mulch treatments significantly and their effect varied with grasses and BLW. Silver oak leaf mulch applied treatment had more BLW while areca nut leaf mulch more grasses.

Table 2. Weed biomass (g/m^2) at end of study under different mulches

Treatment	Weed biomass (g/m^2) on 20 March, 2019		
	Grass	BLW	Total
Areca nut leaf mulch	6.74 (45)	5.46 (29)	8.65 (74)
Areca nut chopped leaf mulch	4.63 (21)	4.38 (19)	6.33 (40)
Areca nut husk mulch	3.43 (11)	5.07 (25)	6.08 (36)
Silver oak leaf mulch	5.70 (32)	5.56 (28)	7.93 (60)
Black polythene mulch	0.71 (0)	0.71 (0)	0.71 (0)
Weedy check	16.30 (265)	8.21 (67)	18.24 (332)
Weed free check (no mulch)	0.71 (0)	0.71 (0)	0.71 (0)
LSD (p=0.05)	1.01	0.58	0.81

Weed biomass (g/m^2) at start of experiment in weed free check: 130.1-43.0-173.1 g for grass, BLW and total

Weed dry weight following the weed count differed significantly among treatments (**Table 2**). Weedy check had 332.2 g/m^2 weed biomass as on 12 March, 2019 and of this 79.9% was of grasses. Areca nut leaf mulch followed silver oak leaf mulch had higher weed biomass than chopped leaf mulch and husk mulch. There was no weed biomass in weed free and black polythene mulch. Weed control efficiency (based on weed biomass) presented in **Table 3** showed significant differences among weed management through mulching and varied from 81.22 to 100%. On account of no weed biomass in polythene and weed free treatments, WCE was 100%. Under polythene (black) mulching, weeds started showing yellowing symptoms within 3 weeks time and in next 3 weeks wilted (white to brown stage) completely. Areca nut chopped leaf mulch had WCE values at par of areca nut husk mulch, though for BLW, former was found significantly more effective to the later. Organic mulches were found effective in grassy weed management (89.0% WCE) than BLW (62% WCE). Overall silver oak and areca nut leaf mulches proved least effective based on WCE. However, silver oak leaf

Table 3. Weed control efficiency (%) as influenced by mulching practices

Treatment	Weed control efficiency (%)		
	Grass	BLW	Total
Areca nut leaf mulch	80.04	56.20	77.63
Areca nut chopped leaf mulch	92.12	72.05	92.93
Areca nut husk mulch	95.74	62.33	89.01
Silver oak leaf mulch	87.94	57.55	81.82
Black polythene mulch	100.0	100.0	100.0
Weedy check	0.0	0.0	0.0
Weed free check (no mulch)	100.0	100.0	100.0
LSD (p=0.05)	5.08	7.23	6.51

mulching was significantly more effective than areca nut leaf mulch (unchopped) for grassy weed management due to better cover of ground. Grassy weeds started growing from vacant spaces of areca nut leaves. The wilted weeds gradually decomposed and acted as manure in 12 weeks period. Complete (100%) exclusion of light under black plastic mulch has arrested the photosynthesis of weeds while respiration continued that resulted in yellowing of leaves and finally their death. Low reflectance of light under black mulch (~5%) in tomato (Fortnum *et al.* 2000) supports the complete light absorption contention of this study. A complete (100%) weed management attained in the current study are also supported by the findings of Gangaiah (2019) with transplanted and direct-seeded rice grown under plastic film mulches.

On account of ineffective ground coverage under organic mulches, light continue to reach the ground and to weeds and their growth/ photosynthesis continued. Chopping up of leaves reduced the light penetration to the ground as compared to unchopped areca nut leaf mulch and areca nut husk mulch also has reduced light penetration to the ground. The differences in light penetration to the ground, weed count, biomass and finally WCE differed among mulches. Under unchopped leaf mulches (areca nut and silver oak leaves), few of the weeds emerged out of mulches and continued their growth. Thus unchopped leaf mulch remained less effective than chopped mulches (leaf and husk). Differential reflectance of light by mulches (aluminium foil > oak leaf mulch >no mulch) reported by Setiawan and Ragsdale (1987) in carrot explains the differential performance of mulches in the current study.

Nutrient removal

The nutrient removal/ha of plantation *i.e.* 1.767 m^2 area of treatment/plant x 1372 plants/ha (2424.3 m^2) by weeds was huge. Weeds in their above ground biomass (6 weedings: 259.1 g/m^2) in weed free treatment contained 33.7- 5.18-38.9 kg/ha of N-P-K. If treatment area of palm is only considered (including bole area of 100 m^2), 24.24% of the above nutrients were removed from tree zone. Nutrient removal would be still higher if root biomass is also accounted (here not considered). Most of this nutrient uptake came from first weeding on account of its high share in total biomass (66.8%). It has been observed that weed biomass produced after first weeding had higher concentration of nutrients than first observation on account of their younger age at removal (30 days). In weedy check, the weed biomass (332.2 g/m^2) recorded on 12th March *i.e.*, a mix of matured and drying grasses and BLW and few newly germinated weeds. Though, it had less nutrient concentration than weed free treatment on account of aging (maturity), but caused higher nutrient removal (38.2-5.7-46.5 kg/ha N-P-K) owing to 28.2% higher biomass. In mulched treatments, the nutrients contained in unremoved weeds (weed free treatment biomass in first weeding is indicator) were controlled and depending on control efficiency got converted into organic manure or retained on the surface as dead / stunted mass. In black plastic mulch treatment, 100% weeds got killed and their biomass was added to soil and is under decomposition since November, 2018.

Moisture conservation

Soil moisture content (%) at two soil depths (0-10 and 10-30 cm) representing weed and weed + crop root soil moisture extracting zones as influenced by mulching practices are presented in **Table 4**. On account of heavy rains (4-7 January, 2019 from Pabuk cyclone), soil moisture was near saturation in January observation in all treatments at both depths and was uniform. It did not vary among treatments at both depths in 15 January, 2019 observation. At

Table 4. Soil moisture content (%) at 0-10 and 10-30 cm soil depths at monthly intervals as influenced mulching and other weed management practices

Treatment	Soil moisture content (%)					
	15 January		14 February		16 March	
	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm
Areca nut leaf mulch (unchopped)	17.4	19.1	12.6	15.5	11.5	13.5
Areca nut leaf mulch (chopped)	17.8	19.0	13.3	16.1	11.8	13.7
Areca nut husk mulch	17.6	19.0	13.2	15.9	12.0	13.9
Silver oak leaf mulch	17.3	18.8	12.9	15.7	11.6	13.7
Black polythene mulch	17.9	19.2	14.0	16.2	12.8	14.1
Weedy check	16.8	18.7	11.5	15.2	09.6	12.7
Weed free check (no mulch)	17.2	19.0	12.3	15.9	10.3	13.0
LSD (p=0.05)	NS	NS	0.94	NS	0.98	NS

subsequent two observations, SMC differed significantly in 0-10 cm depth only. Weedy check plot has lost moisture rapidly between 15 January - 16 March and reached PWP level. Weed free check (no mulch), has second lowest SMC. In March observations, all mulched treatments have significantly higher SMC than weed free and weedy check. Polythene mulched plots recorded highest SMC values, though were at par with other mulched treatments.

In weed free plot, evaporation (E) from the bare soil (top 10 cm) was the only form of water loss besides crop uptake (common to all treatments) at deeper layers. Evaporation got decreased over time on account of source limitation (decreased soil moisture supplies in top layer). It was devoid of any weeds on account of monthly weeding. Thus SMC decreased to PWP in two months in 0-10 cm. In weedy check plots, evapo-transpiration (ET) losses of weeds depleted the soil moisture. ET losses of weedy plots were higher than the E loss from weed free plot. Thus, weed free plots had slightly higher SMC than weedy check. Both these plots were near PWP indicating stress build up for crop. Mulches reduced ET losses of water by way of reducing weed counts and their biomass on one hand and by acting as a physical barrier between atmosphere and soil on other hand has prevented the solar radiation to evaporate water freely. Plastic mulches have completely excluded the water loss from ET by controlling weeds and covering the soil. Residue mulches though controlled the weed menace, but could not effectively cover the soil and E continued due to partial cover of the soil. In deeper layer of soil (10-30 depth), SMC did not differ significantly among the mulched and un-mulched treatments though weedy check had lower values as compared to others. In the current study, most of the weed flora comprised of grasses which roots are confined to the top 5 cm only (BLW and some grasses have roots at deeper layers up to 15 cm) and thus did not impact 10-30 cm depth moisture level much. At this depth, crop uptake was major form of water uptake/loss. Thus all treatments were statistically at par. However, the moisture supplies to top layer for evaporation and uptake by weeds (in proportionate to weed count & and weed biomass) have contributed to lower soil moisture in unmulched and organic residue mulched treatments than plastic mulched ones. Earlier studies indicated higher ET losses in un-mulched (4.96 mm/day) than areca nut husk (4.40 mm/day) and polythene mulched (3.79 mm/day) treatments in areca nut crop (Abdul Khader and Havaangi 1991). The lower SMC of the current study among mulched and un-mulched treatments were corroborated by the above findings.

Cost of treatments

Costs of various mulching treatments were given in **Table 5**. The data reveals that areca nut leaf mulching (un-chopped) was cheapest (` 2300/ha) while polythene mulch was the costliest (` 41095/ha) treatment. Plastic mulch cost was 17.9 times that of un-chopped leaf mulch. When a life span of 5 years is taken for plastic mulch, it becomes cheaper than weed free treatment in which every year weeding cost was incurred. Organic mulches have advantage of becoming manure over time and contributing to crop nutrition. The residues generated from crop on adding regularly may decompose over time and adds to the organic matter of soil, which increases soil water holding capacity and also nutrient supplies to crop from mineralized residues.

Crop performance

In perennial crop, yield recording and relating it to weed/mulch treatments requires longer period of study. In the current study, one harvest was done and did not show any significant differences (with an average bunch weight of 6 kg). This is because, these harvested bunches were formed before the initiation of study and the bunches formed during study period are yet to be harvested. Study will continue further to record the productivity and conversion of organic wastes into manure.

Table 5. Cost of mulching and other weed management practices

Treatment	Cost of mulching (`/ha)		
	Cost of materials	Cost of labour	Total
Areca nut leaf mulch (unchopped)	-	2300	2300
Areca nut leaf mulch (chopped)	-	4600	4600
Areca nut husk mulch	-	4600	4600
Silver oak leaf mulch (includes collection from tree trunk)	-	4600	4600
Black polythene mulch at ` 26.6/palm) + labour	36495	4600	41095
Weedy check (no mulch and no weeding)	-	-	-
Weed free check (no mulch, weed free): 30 man days at 460/day)	-	13800	13800

Only labour cost taken for organic mulches and weed free situation

Conclusion and future line of work

Weeds are a severe menace in plantation crops in Islands that were controlled effectively by black polythene mulch during the rain free period where soil moisture becomes limiting (January-March). However, organic mulches would be ideal, though have lower efficiency with single application. When continuously applied over years, they are likely to become more effective. There is need to do more studies over years to record the impact on yield and to workout economics.

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