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Energy budgeting and economics of weed management in dry direct-seeded rice

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ABSTRACT

A field experiment was conducted at Main Research Station, Hebbal, Bengaluru during *Kharif* 2016 and *Kharif* 2017 to study the effect of different herbicide combinations and weed management methods on yield, energetics and economics of dry direct-seeded rice. The experiment consisted of 12 treatments and replicated thrice in RCBD design. Among various weed management treatments hand weeding at 20, 40 and 60 DAS recorded significantly highest paddy grain and straw yield in hand weeding at 20, 40 and 60 DAS (5.50 and 7.22 t/ha, respectively) and found at par with application of bensulfuron-methyl + pretilachlor as pre-emergence *fb* bispyribac-sodium (5.39 and 7.16 t/ha, respectively). Weedy check recorded significantly lowest yield (1.40 and 2.32 t/ha, respectively). Among the various herbicide combinations, sequential application of bensulfuron-methyl + pretilachlor as pre-emergence *fb* bispyribac-sodium was found to be the most energy and economically efficient weed management strategy in dry direct-seeded rice and had maximum value of total output energy (169090 MJ/ha), net energy returns (157444 MJ/ha), energy use efficiency (14.52), net returns (` 59,276/ha) and benefit cost ratio (2.93).

INTRODUCTION

The weed flora of direct-seeded rice crop is entirely different from that of transplanted crop due to maintenance of saturation moisture at sowing and shallow depths of water up to 3 weeks after sowing. As weeds emerge almost at the same time as that of the crop in wet direct-seeded rice and weed competition with rice crop is greater, hence weed management by herbicide is more crucial (Singh and Singh 2010). Weeds pose a serious threat in DSR by competing for nutrients, light, space and moisture just from the time of emergence and throughout the growing season, whereas, weed seeds germinate after rice transplanting in transplanted rice and compete with the well-established rice seedlings. Energy budgeting of weed management is also important because energy and economics are mutually dependent. There is a close relationship between agriculture, economics and energy. Very scanty information is available on this aspect. Therefore, the present study was undertaken to assess the energy budgeting and economics of weed management in dry direct-seeded rice.

MATERIAL AND METHODS

The field experiment was conducted during *Kharif*, 2016 and 2017 to study the effect of combination of herbicides against complex weed flora, and their effect on growth and yield of dry direct-seeded rice (upland condition). The field study was conducted at the Main Research Station, Hebbal, Bengaluru. The experiment consisted 12 treatments, *viz.* bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron (RM) (60 + 600 *fb* 60 g/ha), oxadiargyl *fb* triafamone + ethoxysulfuron (RM) (100/ *fb* 60 g/ha), pendimethalin *fb* triafamone + ethoxysulfuron (RM) (1000 *fb* 60 g/ha), pyrazo-sulfuron-ethyl *fb* triafamone + ethoxysulfuron (RM) (20 + 60 g/ha), bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (60 + 600 *fb* 25 g/ha), oxadiargyl *fb* bispyribac-sodium (100 *fb* 25 g/ha), pendimethalin (38.7% CS) *fb* bispyribac-sodium (1000 *fb* 25 g/ha), pyrazo-sulfuron-ethyl *fb* bispyribac-sodium (20 *fb* 25 g/ha), pendimethalin *fb* penoxsulam + cyhalofop-butyl (RM) (1000 *fb* 135 g/ha), three mechanical weedings (at 20, 40, 60 DAS), hand weedings (at 20, 40, 60 DAS) and weedy check were tested in a randomized block design with three replications. Rice variety '*MAS 946*' was sown at a spacing of 30 cm between rows and seeds were placed closely between plants and fertilizer level of 100 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha was applied. The pre-emergence and post–emergence herbicides were applied using spray volume of 750 liters/ha and 500 liters/ha with knapsack sprayer having water foam nozzle (WFN). All the agricultural inputs, *viz*. seeds, fertilizers, labour, animals, electricity, machinery, organic manures, chemicals, *etc*. and all the agricultural outputs such as grain and straw will have their own equivalent energy (Mega Joules) values (**Table 1**). Energy balance was calculated by using data on input and output energy. From these, the net energy returns, energy productivity, specific energy and energy use efficiency, were calculated by using the following formulae suggested by Alipour *et al*. (2012).

$$\text{Net energy returns (MJ/ha)} = \text{Output energy} - \text{input energy}$$

$$\text{Energy productivity (kg/MJ)} = \frac{\text{Grain yield (kg/ha)}}{\text{Input energy (MJ/ha)}}$$

$$\text{Specific energy (MJ/kg)} = \frac{\text{Input energy (MJ/ha)}}{\text{Grain yield (kg/ha)}}$$

$$\text{Energy use efficiency} = \frac{\text{Output energy (MJ/ha)}}{\text{Input energy (MJ/ha)}}$$

The price of inputs that were prevailing at the time of their use was considered to work out the cost of cultivation. The cost of cultivation was worked out considering the material input like the seed, manure, fertilizer, herbicides, plant protection chemicals, *etc.* and labour input for all the operations. Treatment wise cost of cultivation was worked out. The prevailing market prices of the paddy at university after harvest was obtained from the Senior Farm Superintendent Office, MRS, Hebbal, Bengaluru, was used for the calculation of gross returns.

RESULTS AND DICUSSION

Weed flora

Predominant category of weed was broad leaved followed by grasses and sedges. Among the weed species, the densities of *Cyperus rotundus, Cynodon dactylon, Digitaria marginata, Ageratum conyzoides, Commelina benghalensis* and *Alternenthra sessilis* were more than other weed species.

Weed density and dry weight

Among different category of weeds, in unweeded control the density and dry weight of broad-leaf weeds (128.5/m^2 and 23.7 g/m^2, respectively) was higher followed by grasses (56.3/m^2 and 11.9 g/m^2, respectively) and sedges (56.3/m^2 and 4.9 g/m^2, respectively) at 90 DAS (**Table 2**). Effective control of weeds was noticed at 90 DAS with application of bensulfuron-methyl + pretilachlor (60 + 600 g/ha) as pre-emergence *fb* bispyribac-sodium (25 g/ha) at 25 DAS followed by bensulfuron-methyl + pretilachlor (60 + 600 g/ha) as pre-emergence *fb* triafamone + ethoxysulfurn (60 g/ha at 25 DAS) as evident from the reduced weed density and dry weight due to broader spectrum of effective herbicides on major weed flora apart from hand weeding. All these herbicide mixtures were superior to weedy control in reducing the weeds' density and dry weight. The results were in conformity with the results obtained by Kumaran *et al.* 2015.

Productivity

The data pertaining to grain and straw yield of dry direct-seeded rice as influenced by different weed management practices has been presented (**Table 1**). The grain and straw yield of dry direct-seeded rice were significantly influenced by different weed management practices. Hand weeding at 20, 40 and 60 DAS recorded highest grain (5.50 t/ha) and straw yield (7.22 t/ha) compared to all the treatments. However, it was statistically at par with bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium, (5.39 and 7.16 t/ha, respectively) and bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn (5.29 and 7.03 t/ha, respectively). It is mainly due to effective management of weeds, which lead to improve the growth and yield parameters of dry direct-seeded rice. These results were in conformity with Singh *et al.* (2016) and Yogananda *et al*. (2017). Whereas, significantly lowest gain yield (1.40 t/ha) and straw yield (2.32 t/ha) was noticed in weedy check due to sever completion by weeds, which affected the growth, nutrient uptake and yield parameters of the crop drastically.

Energetics

The different weed management practices varied in terms of input energy, output energy, net energy returns, energy productivity, specific energy and energy use efficiency. Unweeded check required minimum total input energy (10,600 MJ/ha) because neither hand weeding nor herbicide application was done in this treatment. Among the herbicidal treatments, maximum total input energy (11,682 MJ/ha) was required in plot treated bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn, while minimum total input energy (10,639 MJ/ha) was required in plot treated with oxadiargyl *fb* bispyribac-

Table 1. Equivalent energy (mega joules) values

Inputs	Units	Equivalent energy (mega joules)	Remarks
1. Human labour			
a. Adult man	Man hour	1.96	1 adult woman= 0.8 Adult man
b. Woman	Woman hour	1.57	
2. Bullocks	Pair hour	10.10	Body weight 351-450
3. diesel	1 L	56.31	Includes cost of lubricants
4. Petrol	1 L	46.23	Includes cost of lubricants
5. Electricity	1 HP hr	8.90	
6. Machinary			
a. Electric motor	kg	64.80	
b. Farm machinery (excluding self-propelled machines)	kg	62.70	Weight of the machinery was distributed equally over the total life span of the machinery for the particular operation or crop was worked out
7. Inorganic fertilizer			
a. Nitrogen	kg	60.6	Based on the quantity of N, P_2O_5 and K_2O in the fertilizer, energy input was estimated
b. P_2O_5	kg	11.1	
c. K_2O	kg	6.7	
8. Chemicals	kg	120	
9. Irrigation	Ha-cm	46.02	
10. Rice seeds	kg	14.70	
Outputs			
a. Rice grain	kg	14.70	
b. Rice straw	Kg (dry mass)	12.5	

Source: Mittal *et al.* (1985) and Binning *et al.* (1983).

sodium. Three hand weeded treatment required total input energy of 10789 MJ/ha. Based on the paddy grain and straw yield, treatment wise output energy production was calculated. Hand weeding at 20, 40 and 60 DAS recorded higher output energy (171614 MJ/ha). Whereas, among herbicide treatments, higher total energy output put was noticed in bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (169090 MJ/ha) and it was closely followed by pre-emergence application of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn (164999 MJ/ha) due to higher grain and straw yield compared to other treatments. Weedy check recorded lowest grain and straw yield resulted minimum energy output (49692 MJ/ha) compared to all the treatments.

Net energy returns

Among the various weed management treatments, hand weeding at 20, 40 and 60 DAS recorded higher net energy returns (160825 MJ/ha). Among herbicide combinations higher net energy returns was noticed in bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (157444 MJ/ha) and it was closely followed by pre-emergence application of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn (153317 MJ/ha) due to higher output energy compared to other treatments. Weedy check recoded lowest grain and straw yield hence resulted minimum energy output in obtaining lower net energy returns (39092 MJ/ha) compared to all the treatments.

Energy productivity

The minimum energy productivity was noticed in weedy check (0.13 kg MJ/ha) due to lowest grain yield. Maximum energy productivity was observed in hand weeding at 20, 40 and 60 DAS (0.51 kg MJ/ha). Among the herbicide treatments maximum energy productivity is obtained in bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (0.46 kg MJ/ha) and it is closely followed by pre-emergence application of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn (0.45 kg MJ/ha). Higher paddy grain in these treatments reflected on the energy productivity of dry direct-seeded rice.

Specific energy

Unweeded check recorded maximum specific energy (7.57 MJ/kg) due to lower grain yield. Minimum specific energy was noticed in hand weeding at 20, 40 and 60 DAS (1.96 MJ/kg). Among the herbicidal treatments, bensulfuron methyl + pretilachlor *fb* bispyribac sodium recoded minimum specific energy (2.16 MJ/kg).

Energy use efficiency

The higher energy use efficiency was observed in hand weeding at 20, 40 and 60 DAS (15.91). Among herbicide combinations higher energy use efficiency was noticed bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (14.52) and it is closely followed by pre-emergence application of bensulfuron-methyl + pretilachlor *fb* triafamone +

ethoxysulfurn (14.12) due to higher output energy as a result of higher yield compared to other treatments. Whereas, weedy check recoded lower energy use efficiency (4.69) due to very low yield. Similar results are being observed by Shyam Lal *et al*. 2016.

Economics

The main aim of any agricultural technology is to obtain maximum economic returns per rupee invested. The highest mean cost of cultivation was recorded with hand weeding at 20, 40 and 60 DAS (` 35,010/ha) as compared to all other treatments. This was mainly due to the higter cost of labour and number of labours required for weeding is also more thus increased the cost of production. Hand weeding at 20, 40 and 60 DAS recorded highest gross returns (` 92,052/ha) closely followed by bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (` 90,158/ha) and bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron (` 88,282/ha). Whereas, lowest gross returns were observed with weedy check (` 24,870/ha) due to poor yield. The highest

Table 2. Weeds density and weeds dry weight as influenced by different herbicide combinations in dry direct-seeded rice at 90 DAS (pooled data of 2 years)

Treatment	Weed density (no./m^2)				Weed dry weight (g/m^2)			
	Sedges	Grasses	Broad-leaf	Total	Sedges	Grasses	Broad-leaf	Total
Bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn	2.58(5.7)	1.13(11.7)	1.28(17.0)	1.56(34.3)	1.45(1.1)	1.74(2.0)	2.02(3.1)	0.91(6.2)
Oxadiargyl *fb* triafamone + ethoxysulfuron	4.08(15.7)	1.50(30.0)	1.73(52.0)	2.00(97.7)	1.99(3.0)	2.53(5.4)	3.21(9.3)	1.29(17.7)
Pendimetalin *fb* triafamone + ethoxysulfuron	4.24(17.0)	1.65(42.3)	1.93(83.7)	2.16(143.0)	2.05(3.2)	2.95(7.7)	4.02(15.2)	1.45(26.1)
Pyrazosulfuron-ethyl *fb* triafamone + ethoxysulfuron	4.00(15.0)	1.62(40.0)	1.79(60.0)	2.07(115.0)	1.96(2.9)	2.86(7.2)	3.42(10.7)	1.36(20.7)
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	2.45(5.0)	1.10(10.7)	1.24(15.7)	1.52(31.3)	1.40(1.0)	1.70(1.9)	1.97(2.9)	0.89(5.8)
Oxadiargyl *fb* bispyribac-sodium	3.41(10.7)	1.42(25.0)	1.62(39.7)	1.89(75.3)	1.74(2.0)	2.30(4.3)	2.90(7.5)	1.20(13.8)
Pendimethalin (38.7% CS) *fb* bispyribac-sodium	3.70(12.7)	1.47(27.7)	1.69(47.7)	1.95(88.0)	1.85(2.4)	2.43(4.9)	3.13(8.8)	1.26(16.2)
Pyrazosulfuron-ethyl *fb* bispyribac-sodium	3.36(10.3)	1.37(21.7)	1.62(39.7)	1.87(71.7)	1.73(2.0)	2.20(3.9)	2.88(7.3)	1.18(13.2)
Pendimethalin (38.7% CS) *fb* penoxsulam + cyhalofop-butyl	4.47(19.0)	1.63(41.0)	1.93(84.7)	2.16(144.7)	2.19(3.8)	2.92(7.5)	4.05(15.4)	1.46(26.7)
Three mechanical weedings	4.20(16.7)	1.61(38.7)	1.89(76.0)	2.12(131.3)	2.05(3.2)	2.81(6.9)	3.85(13.8)	1.41(23.9)
Hand weedings	2.38(4.7)	1.05(9.3)	1.22(14.7)	1.49(28.7)	1.38(0.9)	1.64(1.7)	1.92(2.7)	0.86(5.3)
Weedy check	4.54(19.7)	1.77(56.3)	2.12(128.5)	2.31(204.5)	2.43(4.9)	3.58(11.9)	4.96(23.7)	1.63(40.5)
LSD(p=0.05)	0.33	0.14	0.15	0.21	0.21	0.24	0.31	0.16

Data within the parentheses are original values; Transformed values - - # = log (X+2), + = square root of (X+1); DAS = Days after sowing

Table 3. Yield and energetics of dry direct-seeded rice as influenced by different weed management practices (pooled data of 2 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy productivity (Kg/MJ)	Specific energy (MJ/kg)	Energy use efficiency
Bensulfuron methyl + pretilachlor *fb* triafamone + ethoxysulfurn	5.29	7.03	11682	164999	153317	0.45	2.21	14.12
Oxadiagyl *fb* triafamone + ethoxysulfuron	4.39	6.14	10675	141646	130971	0.41	2.43	13.27
Pendimetalin *fb* triafamone + ethoxysulfuron	4.15	6.09	10925	137473	126548	0.38	2.63	12.58
Pyrazosulfuron ethyl *fb* triafamone + ethoxysulfuron	4.32	6.15	10687	140787	130100	0.40	2.47	13.17
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	5.39	7.16	11646	169090	157445	0.46	2.16	14.52
Oxadiargyl*fb* bispyribac-sodium	4.42	6.11	10639	141765	131127	0.42	2.41	13.33
Pendimethalin (38.7% CS) *fb* bispyribac sodium	4.43	6.11	10889	141913	131024	0.41	2.46	13.03
Pyrazosulfuron ethyl *fb* bispyribac sodium	4.48	6.20	10651	143777	133126	0.42	2.38	13.50
Pendimethalin(38.7% CS) *fb* penoxsulam + cyhalofop-butyl	4.15	6.13	10869	138098	127229	0.38	2.62	12.71
Mechanical weedings	4.38	6.19	10977	141975	130998	0.40	2.51	12.93
Hand weedings	5.50	7.22	10789	171614	160825	0.51	1.96	15.91
Weedy check	1.40	2.32	10600	49692	39092	0.13	7.57	4.69
LSD (p=0.05)	0.62	0.97	NA	NA	NA	NA	NA	NA

NA: Not Analyzed

Table 4. Economics of dry direct-seeded rice as influenced by different weed management practices (pooled data of 2 years)

Treatment	Cost of cultivation (x10^3 `/ha)	Gross returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	B:C ratio
Bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfurn	30.75	88.28	57.53	2.88
Oxadiagyl *fb* triafamone + ethoxysulfuron	29.58	74.48	44.90	2.52
Pendimetalin *fb* triafamone + ethoxysulfuron	29.48	71.24	41.76	2.42
Pyrazosulfuron-ethyl *fb* triafamone + ethoxysulfuron	30.01	73.55	43.54	2.45
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	30.88	90.16	59.28	2.93
Oxadiargyl *fb* bispyribac-sodium	30.58	74.86	44.28	2.45
Pendimethalin (38.7% CS) *fb* bispyribac-sodium	30.67	75.01	44.34	2.45
Pyrazosulfuron-ethyl *fb* bispyribac-sodium	29.56	75.94	46.38	2.58
Pendimethalin (38.7% CS) *fb* penoxsulam + cyhalofop-butyl	30.69	71.55	40.86	2.33
Mechanical weedings	31.94	74.58	42.64	2.34
Hand weedings	35.01	92.05	57.04	2.63
Weedy check	26.78	24.87	-1.91	0.93

net returns and B:C ratio was obtained in application of bensulfuron-methyl + pretilachlor as PE *fb* bispyribac-sodium at 25 DAS (` 59,276/ha and 2.93, respectively) and closely followed by PE application of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron at 25 DAS (` 57,533/ha and 2.88) due to improved yield and reduced cost of weed management while it was ` 57,042/ha and 2.63, respectively in hand weeding plots due to increased cost of cultivation. The lowest B:C ratio (0.93) was obtained in the weedy check plots along with negative net returns (` -1,912/ha). Herbicide technology offered an alternative method of selective and economical control of weeds right from the beginning, giving crop an advantage of good start and competitive superiority and found to be cheaper than hand weeding for effective management of weeds and economic returns in dry direct-seeded rice. These results are in harmony with the findings of Vijay Singh *et al.* (2016), Prameela *et al.* (2014) and Yogananda *et al.* (2017).

From this study, it was revealed that pre-emergence application of bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium found to be the best herbicide combination for higher productivity, energy and economically efficient weed management strategy in dry direct-seeded rice cultivation.

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Weed management effect to increase grain yield in dry direct-seeded rice

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ABSTRACT

An experiment was conducted during *Kharif* 2016 and 2017 at Agricultural Research Station, Dhadesugur, University of Agricultural Sciences, Raichur, Karnataka, India, to study the bio-efficacy of weed control practices on weeds and grain yield of dry-seeded rice. The dominant grassy weeds in fields were *Echinochloa* sp. *Panicum repens, Cynodon dactylon, Bracharia mutica, Digitarias sanguinalis, Commelina communis* and *Leptochloa chinensis*. Broad-leaf weeds were *Eclipta alba*, and *Ludwigia parviflora* and *Cyperus* sp. as sedge. Results revealed that, pre-emergence application of pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha) recorded significantly lower weed dry weight at 15, 30 and 45 DAS during *Kharif* 2016 and 2017, higher weed control efficiency at 15, 30 and 45 days after sowing (DAS) (82.6, 80.2 and 80.6% during *Kharif* 2016 and 82.1, 82.7 and 80.2%, respectively during *Kharif* 2017, respectively) and higher rice grain yield (4.92 and 4.98 t/ha during *Kharif* 2016 and 2017, respectively) and which was at a par with twice hand weeding at 20 and 40 DAS.

INTRODUCTION

Among several reasons for low rice productivity, the losses due to weeds are one of the most important. Weeds are most severe and widespread biological constrains to crop production in India and alone cause 33% of losses out of total losses due to pests (Verma *et al.* 2015). Irrespective of the method of rice establishment, weeds are a major impediment to rice production due to their ability to compete for resources. In general, weeds problem in transplanted paddy is lower than that of direct-seeded rice (Rao *et al.* 2007). But in situations where continuous standing water cannot be maintained particularly during the first 45 days, weed infestation in transplanted rice also may be as high as direct-seeded rice. According to Singh *et al.* (2004), weeds can reduce the grain yield of dry-seeded rice (DSR) by 75.8%, wet-seeded rice (WSR) by 70.6% and transplanted rice (TPR) by 62.6%. Weeds by virtue of their high adaptability and faster growth dominate the crop habitat and reduce the yield potential. Therefore, the present investigation was undertaken to study the effect of early post-emergent herbicide for control of major weeds in irrigated dry-seeded rice.

MATERIALS AND METHODS

A field experiment was taken during *Kharif* 2016 and 2017 on effect of weed control practices on bio-efficacy of weeds and grain yield of dry-seeded rice at Agricultural Research Station, Dhadesugur, Raichur, Karnataka. The soil of the experimental site was medium deep black and neutral in pH (8.04), EC (0.47 ds/m), medium in organic carbon content (0.41%), low in nitrogen (189 kg/ha), medium in phosphorus (58.5 kg/ha) and potassium (287.5 kg/ha). There were eight treatments, *viz*. bispyribac-sodium (25 g/ha), penoxusulam (25 g/ha), azimsulfuron (35 g/ha), pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha), pyrazosulfuron-ethyl (20 g/ha), 2,4-D Na Salt (1000 g/ha), hand weeding at 20 and 40 DAS and weedy check and these treatments were replicated thrice. Herbicides were sprayed using a knapsack sprayer fitted with a flat-fan nozzle at a spray volume of 500 l/ha. Rice was sown by tractor drawn seed drill at spacing of 20 cm (between the rows) in both the years. Recommended dose of fertilizer (150:75:75 kg NPK/ha) was applied uniformly in three equal splits. Irrigation comprised of alternate drying and wetting followed by intermittent irrigation at seven days interval up to 15 days before harvest. Other agronomic and plant protection measures were adopted as recommended during the crop growth. The efficacy of different treatments on weeds was evaluated at crop maturity. Quadrates (0.25 m^2) were placed in each plot at random to determine the weed density. Weed seedlings within these quadrates were counted and the efficacy of weed control treatments was evaluated by comparing the density with the untreated control. Weeds were cut at ground level, washed with tap water, oven dried at 70 ^{0}C for 48 hours and then weighed for biomass. The weed control efficiency was calculated using the formula given by Tawaha *et al.* (2002). After harvest and threshing of crop, grain yield was recorded in net plot wise and converted to grain yield per hectare. The data of each year was analyzed separately. MSTAT was used for statistical analysis of data and means were separated using critical difference (CD) at p=0.05. The data on weeds were transformed by square root transformation by adding one before being subjected to ANOVA (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect on weed density and dry weight of weeds

The predominant grassy weeds in field were *Echinochloa* sp. *Panicum repens, Cynodon dactylon, Bracharia mutica, Digitarias sanguinalis* and *Leptochloa chinensis*. Pre-emergence application of pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha) and twice hand weeded check recorded significantly lower grassy weeds compared to other weed control treatments and weedy check in *Kharif* 2016 and 2017 when observed at 15, 30 and 45 DAS. Singh *et al.* (2007) reported that early post-emergence application of penoxsulam recorded significantly lower grassy weed population in rice. Similarly, Yadav *et al.* (2007) have also reported penoxsulam as an effective post-emergence herbicide against mixed weed flora in rice. The predominant broad-leaf weeds in the trials field were *Eclipta alba, Commelina communis* and *Ludwigia parviflora*. Pre-emergence application of pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha) and twice hand weeded check found to be significantly superior treatment with recorded lowest population of broad-leaf weeds over rest of the treatments. Further, weedy check recorded significantly higher weed population of broad-leaf weeds. These results were in conformity with the findings of Yadav *et al.* (2007). Pre-emergence application of pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha) and twice hand weeded check were found equally effective in controlling sedges in direct-seeded rice (**Table 1** and **2)**. Weedy check recorded

Table 1. Effect of weed control treatments on weed counts in direct-seeded rice (*Kharif* 2016)

Treatment	Grasses (no./m^2)			Broad-leaf weeds (no./m^2)			Sedges (no./m^2)		
	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS
Bispyribac-sodium (25 g/ha)	2.41(4.80)	2.02(3.10)	2.06(3.26)	2.12(3.50)	2.20(3.84)	1.91(2.65)	1.84(2.40)	2.40(4.78)	2.05(3.21)
Penoxusulam (25 g/ha)	2.43(4.90)	2.07(3.29)	2.29(4.26)	2.15(3.62)	2.20(3.86)	2.28(4.21)	1.90(2.61)	2.49(5.21)	2.67(6.12)
Azimsulfuron (35 g/ha)	2.43(4.92)	2.10(3.40)	2.29(4.25)	2.17(3.71)	2.17(3.72)	2.42(4.85)	1.93(2.71)	2.52(5.35)	2.58(5.65)
Pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha)	1.88(2.54)	1.97(2.89)	2.06(3.25)	2.05(3.21)	1.11(0.24)	1.46(1.12)	1.78(2.16)	1.50(1.26)	1.50(1.25)
Pyrazosulfuron-ethyl (20 g/ha)	2.03(3.12)	2.07(3.28)	2.28(4.21)	1.95(2.82)	2.22(3.92)	2.29(4.26)	1.73(2.00)	2.42(4.85)	2.54(5.45)
2,4-D, Na Salt at 1000 g/ha)	2.43(4.91)	2.06(3.25)	2.36(4.56)	2.15(3.62)	2.21(3.89)	2.38(4.65)	1.98(2.92)	2.42(4.86)	2.49(5.21)
Hand weeding at 20 and 40 DAS	2.29(4.25)	1.45(1.10)	1.80(2.25)	2.48(5.13)	1.52(1.32)	1.42(1.01)	1.79(2.21)	1.59(1.52)	1.41(1.00)
Weedy check	2.26(4.12)	4.40(18.4)	4.72(21.3)	2.20(3.82)	4.05(15.4)	4.31(17.6)	1.77(2.12)	3.08(8.48)	3.20(9.21)
LSD (p=0.05)	0.35	0.38	0.42	0.52	0.52	0.48	0.65	0.63	0.48

Figures in outside the parentheses are square root transformed values ($\sqrt{x+1}$); DAS - Days after sowing

Table 2. Effect of weed control treatments on weed counts in direct-seeded rice (*Kharif* 2017)

Treatment	Grasses (no./m^2)			Broad-leaf weeds (no./m^2)			Sedges (no./m^2)		
	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS
Bispyribac-sodium (25 g/ha)	2.41(4.82)	2.08(3.31)	2.07(3.27)	2.13(3.52)	2.23(3.98)	1.92(2.67)	1.85(2.42)	2.43(4.92)	2.14(3.56)
Penoxusulam (25 g/ha)	2.43(4.91)	2.08(3.32)	2.30(4.29)	2.15(3.64)	2.21(3.89)	2.29(4.26)	1.93(2.71)	2.50(5.24)	2.74(6.51)
Azimsulfuron (35 g/ha)	2.44(4.94)	2.13(3.52)	2.30(4.28)	2.17(3.73)	2.21(3.89)	2.43(4.89)	1.96(2.84)	2.50(5.24)	2.60(5.74)
Pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha)	1.87(2.51)	1.98(2.91)	2.06(3.26)	1.77(2.15)	1.12(0.25)	1.47(1.15)	1.77(2.14)	1.51(1.29)	1.51(1.29)
Pyrazosulfuron-ethyl (20 g/ha)	2.04(3.15)	2.08(3.31)	2.29(4.23)	1.84(2.38)	2.26(4.12)	2.30(4.28)	1.83(2.11)	2.43(4.89)	2.55(5.48)
2,4-D, Na Salt at 1000 g/ha)	2.43(4.92)	2.14(3.56)	2.36(4.57)	2.17(3.71)	2.22(3.92)	2.39(4.69)	1.99(2.95)	2.43(4.92)	2.51(5.32)
Hand weeding at 20 and 40 DAS	2.49(5.21)	1.49(1.21)	1.81(2.26)	2.28(4.18)	1.50(1.25)	1.43(1.05)	1.77(2.14)	1.62(1.61)	1.50(1.25)
Weedy check	2.28(4.21)	4.49(19.2)	4.85(22.5)	2.20(3.82)	4.15(16.2)	4.37(18.1)	1.82(2.32)	3.20(9.25)	3.20(9.26)
LSD (p=0.05)	0.26	0.32	0.54	0.56	0.24	0.65	0.42	0.54	0.32

Figures in outside the parentheses are square root transformed values ($\sqrt{x+1}$); DAS - Days after sowing significantly higher sedges density as compared to other weed controlling treatments. These results were in conformity with the findings of Jabusch *et al.* (2005) and Jason *et al.* (2007).

Pre-emergence application of pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha) and twice hand weeded check found to be significantly superior to the rest of the treatments in controlling the weeds and recorded least weeds dry weight. Further, weedy check recorded significantly higher dry weight of weeds compared to other weed controlling treatments **(Table 3)**. These results were in conformity with the findings of Mishra *et al.* (2007) and Nandal *et al.* (1999).

Effect on weed control efficiency (WCE) and grain yield

Significantly higher weed control efficiency was recorded in the treatments with the pre-emergence application of pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha) and twice hand weeded check (**Table 4**). However, post-emergence application of bispyribac-sodium (250 ml/ha), penoxusulam (104 g/ha), azimsulfuron (70 g/ha), pyrazosulfuron-ethyl (200 g/ha) and 2,4-D Na Salt (1.25 kg/ha) were at par with each other in recording weed control efficiency. These results were in conformity with the findings of Jabusch *et al.* (2005) and Jason *et al.* (2007).

Table 3. Effect of weed control treatments on dry weight of weeds (g) in direct-seeded rice

Treatment	*Kharif* 2016			*Kharif* 2017		
	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS
Bispyribac-sodium (25 g/ha)	5.01(24.1)	3.08(8.5)	3.67(12.5)	5.10(25.0)	3.16(9.0)	3.41(10.6)
Penoxusulam (25 g/ha)	5.13(25.3)	3.32(10.0)	3.90(14.2)	5.10(25.0)	3.49(11.2)	3.82(13.6)
Azimsulfuron (35 g/ha)	5.20(26.0)	3.61(12.0)	4.02(15.2)	5.00(24.0)	3.58(11.8)	4.15(16.2)
Pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha)	2.07(3.30)	2.55(5.5)	3.09(8.5)	2.02(3.10)	2.63(5.9)	3.09(8.6)
Pyrazosulfuron-ethyl (20 g/ha)	2.14(3.60)	3.10(8.6)	3.39(10.5)	2.24(4.00)	2.81(6.9)	3.46(11.0)
2,4-D, Na Salt at 1000 g/ha)	5.10(25.0)	3.32(10.0)	4.02(15.2)	5.20(26.0)	3.63(12.2)	3.94(14.5)
Hand weeding at 20 and 40 DAS	5.20(26.0)	1.73(2.0)	1.76(2.1)	5.00(24.0)	1.58(1.5)	1.67(1.8)
Weedy check	5.10(25.0)	6.67(43.5)	7.43(54.2)	5.39(28.0)	6.52(41.5)	7.52(55.6)
LSD (p=0.05)	1.20	1.20	1.25	1.12	1.42	1.31

Figures in outside the parentheses are square root transformed values ($\sqrt{x+1}$); DAS - Days after sowing

Table 4. Effect of weed control treatments on weed control efficiency (%) in direct-seeded rice

Treatment	*Kharif* 2016			*Kharif* 2017		
	15 DAS	30 DAS	45 DAS	15 DAS	30 DAS	45 DAS
Bispyribac-sodium (25 g/ha)	6.59	80.5	76.9	10.7	78.3	80.9
Penoxusulam (25 g/ha)	1.94	77.0	73.8	10.7	73.0	75.5
Azimsulfuron (35 g/ha)	5.04	72.4	72.0	14.3	71.6	70.9
Pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha)	87.2	87.4	84.3	88.9	85.8	84.5
Pyrazosulfuron-ethyl (20 g/ha)	82.6	80.2	80.6	82.1	82.7	80.2
2,4-D, Na Salt at 1000 g/ha)	3.10	77.0	72.0	7.14	70.6	73.9
Hand weeding at 20 and 40 DAS	5.04	95.4	96.1	14.3	96.4	96.8
Weedy check	-	-	-	-	-	-
LSD (p=0.05)	4.45	6.54	3.21	5.68	2.56	3.85

Table 5. Effect of weed control treatments on growth and grain yield of direct-seeded rice

Treatment	*Kharif* 2016			*Kharif* 2017		
	Tillers/m^2	Grains/ panicle	Grain yield (t/ha)	Tillers/m^2	Grains/ panicle	Grain yield (t/ha)
Bispyribac-sodium (25 g/ha)	200	212	5.01	202	221	5.14
Penoxusulam (25 g/ha)	199	211	4.90	200	218	4.95
Azimsulfuron (35 g/ha)	196	205	4.62	197	212	4.81
Pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha)	215	215	5.78	217	225	5.84
Pyrazosulfuron-ethyl (20 g/ha)	199	210	4.92	201	217	4.98
2,4-D, Na Salt at 1000 g/ha)	197	208	4.76	198	209	4.97
Hand weeding at 20 and 40 DAS	220	222	5.89	221	232	5.92
Weedy check	188	158	2.98	186	162	3.25
LSD (p=0.05)	4.52	2.25	0.11	3.65	3.21	0.085

During both the seasons **(Table 5**), twice hand weeding at 20 and 40 days after sowing recorded significantly higher rice grain yield (5.89 and 5.92 t/ha in *Kharif* 2016 and 2017, respectively) and which was at par with pre-emergence application of pretilachlor + pyrazosulfuron-ethyl (600 + 15 g/ha) (5.78 and 5.84 t/ha in *Kharif* 2016 and 2017, respectively). These results were conformity with the findings of Yadav *et al.* (2007) which stated the effectiveness states that, Efficacy of penoxsulam in controlling weeds and increasing rice grain yield. Similar findings were also reported by Ramesha *et al.* (2017), who recorded, post-emergence application of penoxsulam 10 g/l + bentazone 360 g/l SC (2500 ml/ ha) effective control weeds and to obtain higher grain yield in irrigated dry-seeded rice.

It was concluded that pre-emergence application of pretilachlor + pyrazosulfuron ethyl (600 + 15 g/ha) was found most effective treatment for control of weeds in dry direct-seeded rice.

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Penoxsulam influence on weed complex and productivity of transplanted rice and its residual effects in rice-wheat cropping system

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ABSTRACT

Field experiments were conducted to evaluate the bio-efficacy of penoxsulam 2.67% w/w (2.5% w/v) OD applied as post-emergence (PoE) in transplanted rice and its residual effect in succeeding wheat crop at CCS Haryana Agricultural University, Regional Research Station, Karnal. Penoxsulam 22.5 g/ha reduced the density (0.0 to 0.7/m^2) and dry weight (0.0 to 6.3 g/m^2) of grassy weeds during 2011 and 2012 and was similar to weed free check. Penoxsulam at 22.5 g/ha resulted in similar dry weight of grassy and broad-leaf weeds with all other herbicidal treatments, and was superior to bispyribac-sodium 20 g/ha in controlling grassy weeds during 2012 and bispyribac-sodium 20-25 g/ha in controlling broad-leaf weeds during both the years. It provided almost complete control of sedges. The grain yield under penoxsulam 22.5 g/ha (5.68 t/ha in 2011 and 6.89 t/ha in 2012) was at par with its higher dose (25 g/ha) and more than its lower dose (20 g/ha). It also resulted in net returns (` 31921-55372/ha) and B:C ratio (2.03-2.68) almost similar/higher to recommended post-emergence herbicides. Weeds growing throughout the crop season reduced the grain yield of rice to the tune of 37.5 and 43.4% during 2011 and 2012, respectively. Penoxsulam 22.5 g/ha also performed well against weed complex in adaptive trials at farmers' fields during *Kharif* 2017. There was no phyto-toxicity of penoxsulam even up to 50 g/ha on transplanted rice crop and also there was no residual phyto-toxicity on the succeeding wheat during 2011-12 to 2013-14. It also did not leave any detectable residual carry-over at harvest in soil, straw and rice grain when applied up to 45 g/ha.

INTRODUCTION

Rice is the staple food of more than 60% of the world population and there is urgent need to increase productivity and production to meet the food demands of the consistently growing population (Fageria 2007). It is grown in India over an area of 44 m ha with total production of 105 m tones, amounting to 40% of the total food grain (Economic Survey 2015-16). Productivity of rice is low in the country and among different constraints, weeds pose a major threat. Weed infestation in transplanted rice in India has been reported to cause yield reductions of 27-68% (Yadav *et al.* 2009, Manhas *et al.* 2012, Duary *et al.* 2015, Hossain and Malik 2017). Most of the already recommended herbicides (butaclor, pretilachlor, anilofos and oxadiargyl) are applied as pre-emergence. However, sometimes the pre-emergence (PE) herbicides do not perform well particularly under water scarce conditions immediately after transplanting. Hence, need was felt for post-emergence herbicides for control of complex weed flora in transplanted rice. Penoxsulam 24% SC has already been reported very effective for control of complex weed flora in transplanted rice (Mishra *et al.* 2007, Yadav *et al.* 2008), but with limited acceptability and use by the farmers as its recommended application window of 8-12 days after transplanting (DAT) as spray in puddle transplanted rice fields could be too early to be practically followed. Bispyribac-sodium is being most commonly used for post-emergence control of weeds in transplanted rice (Yadav *et al.* 2009). However, some of grassy and broad-leaf weeds and sedges are not controlled effectively by alone application of these herbicides. Penoxsulam 2.5% OD is a new herbicide formulation for post-emergence weed control in transplanted rice. Therefore, an investigation was conducted to optimize the dose and time of application of penoxsulam against complex weed flora in transplanted rice, along with its evaluation at farmers' fields, and residual carry over in soil, straw and grains of rice.

MATERIALS AND METHODS

Field experiments were conducted to evaluate the bio-efficacy of penoxsulam 2.67% w/w (2.5% w/v) OD in transplanted rice at CCS Haryana Agricultural University, Regional Research Station, Karnal during *Kharif* 2011 and 2012, its phyto-toxicity on rice crop and succeeding wheat crop during 2011-12 to 2013-14, residue analysis in *Kharif* 2017 and multi-locational adaptive trials at farmers' fields during *Kharif* 2017.

On-station experiments

Bio-efficacy studies: A field experiment was conducted to evaluate the bio-efficacy of penoxsulam 2.67% w/w (2.5% w/v) OD applied as post-emergence (PoE) in transplanted rice at CCS Haryana Agricultural University, Regional Research Station, Karnal during *Kharif* 2011 and 2012. The soil of the experimental field was clay loam in texture, low in available N, medium in P_2O_5 and high in available K_2O with slightly alkaline reaction (pH 8.2). The treatments included penoxsulam 2.5% OD 20, 22.5, 25 g/ha at 15-20 DAT, check herbicides penoxsulam 24% SC 22.5 g/ha at 8-12 DAT, bispyribac-sodium 10% SC 20 g/ha at 10-14 DAT, bispyribac-sodium 25 g/ha at 15-25 DAT (during 2012), butachlor 50% EC 1500 g/ha at 0-3 DAT, along with weed free and weedy checks. The experiment was laid out in randomized block design with three replications. Transplanting of rice cultivar '*HKR 47*' (40 and 36 days old nursery in 2011 and 2012, respectively) was done at spacing of 20 x 15 cm on 20 July and 12 July during 2011 and 2012, respectively. The plot size was 6.1 x 2.4 m. The post-emergence (PoE) herbicides were applied as spray using knap-sack sprayer fitted with flat fan nozzle in a spray volume of 300 litres/ha, and the pre-emergence (PE) herbicides as sand mix broadcast using 150 kg sand/ha. The soil in field was kept under saturated condition during spray application and re-irrigated after 24 hours of spray application. Crop was raised as per the recommendations of the state University and harvested on 30 October, 2011 and 22 October, 2012. Density and dry weight of weeds were recorded at 60 days after transplanting (DAT) and yield and yield attributes at maturity. Crop injury in respect of phyto-toxicity symptoms (yellowing, chlorosis, stunting or scorching) under different treatments was also recorded by visual rating (0-100%) at 15, 30 and 45 days after herbicide application (DAA). Since, there was no crop injury on rice crop and subsequent wheat data pertaining to this aspect are not included herein.

Phyto-toxicity studies: Another field experiment was conducted to study the phyto-toxicity of penoxsulam 2.5% OD on transplanted rice at CCS Haryana Agricultural University, Regional Research Station, Karnal during *Kharif* 2011 to 2013. The treatments included application of penoxsulam at 25 and 50 g/ha at 15-20 DAT along with untreated check with three replications. During *Kharif* 2011, 2012 and 2013, 40, 36 and 35 days old nursery of rice cv. '*HKR-47*' were transplanted on 20 July, 12 July and 7 July, respectively. The other agronomic practices and spray methodology were same as that adopted for bio-efficacy experiment. Transplanting was done at a spacing of 20 x 15 cm in a plot size of 6.1 x 2.4 m. Herbicides were applied by spray with knapsack sprayer fitted with flat fan nozzle using 300 liter water/ha. Crop was harvested on 30 October, 2011 and 22 October, 2012 and 21 October 2013. Observations (from 10 plants/plot) on crop phyto-toxicity in rice terms of vein clearing, epinasty, hyponasty, wilting and injury to leaf tips and leaf surface were recorded at 1, 3, 5, 7, 10, 15 and 30 days after herbicide application (DAA), on 0-10 point scale, with 0= no phyto-toxicty and 10= compete mortality.

Wheat crop was sown on the same plots after rice on 25 November 2011 (*DPW 621-50*), 20 November 2012 (*DPW 621-50*) and 17 November 2013 (*WH 711*) using seed rate of 100-112.5 kg/ha at row spacing of 20 cm. Crop was raised as per package of practices of the state university. Observations from 10 plants/plot on crop phyto-toxicity were recorded at 15 and 30 DAS on 0-10 point scale with 0= no phyto-toxicity and 10= complete mortality.

Residue studies: Residual studies in soil as well as straw and grains of rice were conducted during *Kharif* 2017 for the standard grade made available by the manufacturer company during this season. The treatments included penoxsulam 2.5% OD at 22.5 (X), 45.0 g/ha (2X) applied at 15-20 DAT and untreated check. Rice cv. '*HKR 47*' was transplanted on 13 July at a spacing of 20 x 15 cm in a plot size of 16.0 x 6.0 m. Herbicides were applied by spray with knapsack sprayer fitted with flat fan nozzle using 300 liter water/ha. Crop raised as per the recommendations of the CCS HAU was harvested on 20 October. The harvest time samples of grain, straw and soil were analysed for residue estimation of penoxsulam by using HPLC.

On-farm adaptive trials: Adaptive trials at farmers' fields were conducted at 12 locations in Karnal, Kurukshetra and Panipat districts during *Kharif* 2017 with commercial product of penoxsulam 2.5% OD made available by the manufacturing company. The fields were infested with complex weed flora comprising grassy weeds, broadleaf weeds and sedges. Penoxsulam at 22.5 g/ha at 15-20 DAT was evaluated in comparison to the check herbicide bispyribac-sodium at 25 g/ha at 15-25 DAT. Herbicides were applied as spray in 300 litres water/ha. The area under each treatment was 0.2 ha at each site.

Statistical analysis

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

RESULTS AND DISCUSSION

On-Station experiments

Effect on weeds: Application of penoxsulam 2.5% OD 22.5 g/ha at 15-20 DAT significantly reduced the density (0.0-0.7/m^2) and dry weight (0.0-6.3 g/m^2) of grassy weed *Echinochloa* spp. than its lower dose (20 g/ha), but was at par with its higher dose of 25 g/ha (**Table 1 and 2**). It resulted in density of grassy weeds similar to check herbicides penoxsulam 24% SC 22.5 g/ha, butachlor 1500 g/ha and weed free check during both the years; bispyribac-sodium 20 g/ha during 2011 and bispyribac-sodium 25 g/ha during 2012. It resulted in significantly lower dry weight of grassy weeds than with bispyribac-sodium 20 g/ha during 2012, and was at par with all other herbicidal treatments. During both the years, penoxsulam 22.5 g/ha resulted in statistically similar density of broad-leaf weeds (BLW) (19.3-32.7/m^2) with all its other doses, and check herbicides penoxsulam 24% SC 22.5 g/ha and butachlor 1500 g/ha during 2011 (**Table 1**). However, this treatment was inferior to butachlor during 2012. Penoxsulam 22.5 g/ha was also superior to bispyribac-sodium 20-25 g/ha, in reducing the density as well as dry weight of broad-leaf weeds during both the years. However, it was inferior to weed free conditions during both the years.

Penoxsulam 2.5% OD 22.5 g/ha resulted in lower dry weight of broad-leaf weeds) (0.8-1.2 g/m^2) than its dose of 20 g/ha, but further reduction with its higher dose of 25 g/ha was not significant (**Table 2**). Penoxsulam 22.5 g/ha provided almost complete control of sedges, and was at par with all other weed control treatments except weedy check, which registered significantly lower density and dry weight of sedges during both the years, and bispyribac 25 g/ha for density of sedges in 2011 (**Tables 1 and 2**). Penoxsulam 24% SC 20.0-22.5 g/ha applied at 10-12 DAT was found very effective in controlling *E. crus-galli*, *E. colona*, *A. baccifera*, *Euphorbia* sp., *Fimbristylis miliaceae* and *Cyperus rotundus* in transplanted rice (Yadav *et al.* 2008). Penoxsulam 22.5 g/ha, another formulation of penoxsulam was found very effective against complex weed flora besides providing wider window of its application. Bispyribac-sodium was very effective against grasses particularly *E. crusgalli* and *E. colona*, but control of broad-leaf weeds and sedges was poor (Yadav *et al.* 2009). Therefore, penoxsulam could be suitable alternative under those situations where broad-leaf weeds and sedges dominate.

Effect on crop: There was no significant effect of different herbicidal treatments on the plant height and panicle length of rice during both the years (**Table 3**). Penoxsulam 2.5% OD 22.5 g/ha resulted in effective

Table 1. Effect of penoxsulam 2.5% OD on density of weeds (no./m^2) at 60 DAT in transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Time (DAT)	Grassy weeds		Broad-leaf weeds		Sedges	
			2011	2012	2011	2012	2011	2012
Penoxsulam	20	15-20	2.51(5.3)	2.20(4.0)	6.33(39.3)	5.50(30.0)	1.0(0)	1.0(0)
Penoxsulam	22.5	15-20	1.24(0.7)	1.0(0)	5.77(32.7)	4.33(19.3)	1.0(0)	1.0(0)
Penoxsulam	25	15-20	1.00(0.0)	1.0(0)	5.69(31.3)	4.33(18.7)	1.0(0)	1.0(0)
Penoxsulam (check)	22.5	8-12	1.55(2.0)	1.0(0)	5.79(32.7)	3.91(14.7)	1.0(0)	1.0(0)
Bispyribac-sodium	20	14	1.90(2.7)	1.96(3.3)	8.87(78.0)	7.80(60.0)	2.04(5.3)	1.0(0)
Bispyribac-sodium	25	15-25	-	1.0(0)	-	7.55(56.0)	-	1.0(0)
Butachlor	1500	0-3	1.00(0.0)	1.0(0)	4.93(23.3)	1.0(0)	1.0(0)	1.0(0)
Weed free			1.00(0.0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy check			4.50(19.3)	6.14(36.7)	10.03(100.0)	8.91(78.7)	5.43(29.3)	1.96(3.3)
LSD (p=0.05)			0.73	0.64	0.87	1.24	1.47	0.44

*Original figures in parentheses were subjected to square root $(\sqrt{x+1})$ transformation before statistical analysis tillers/mrl (57.5 in 2011 and 82.7 in 2012) on par with all other treatments except penoxsulam 20 g/ha in 2012 and weedy check during both the years, which registered lower number of effective tillers/mrl. The grain yield under penoxsulam 22.5 g/ha (6.58 t/ha in 2011 and 6.89 t/ha in 2012) was higher than its lower dose (20 g/ha) and at par with higher dose (25 g/ha) during both the years. Grain yield of rice with penoxsulam 2.5% OD 22.5 g/ha was similar to penoxsulam 24% SC 22.5 g/ha, bispyribac-sodium 20 g/ha and 25 g/ha, butachlor 1500 g/ha and weed free check (5.90 t/ha in 2011 and 6.98 t/ha in 2012); and higher than weedy check. Studies conducted elsewhere also revealed that penoxsulam 24% SC 20.0-22.5 g/ha improved yield attributes and yield of transplanted rice due to effective control of complex weed flora (Jason *et al.* 2007, Mishra *et al.* 2007, Yadav *et al.* 2009). Weeds allowed to grow throughout the crop season reduced the grain yield of transplanted rice to the extent of 37.5% and 43.4% during 2011 and 2012, respectively. This is in agreement with earlier findings where yield reductions of 27-68% due to weeds have been reported in transplanted rice (Yadav *et al.* 2009, Manhas *et al.* 2012, Duary *et al.* 2015, Hossain and Malik 2017)

Economics

Penoxsulam 2.5% OD 22.5 g/ha offered net returns of ` 31921-55372/ha, which was almost similar/higher to already recommended PoE herbicide penoxsulam 24% SC 22.5 g/ha (` 30700-55042/ha).

Table 2. Effect of penoxsulam 2.5% OD on dry weight of weeds (g/m^2) at 60 DAT in transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Time (DAT)	Grassy weeds		Broad-leaf weeds		Sedges	
			2011	2012	2011	2012	2011	2012
Penoxsulam	20	15-20	34.1	19.4	2.6	1.6	0.0	0.0
Penoxsulam	22.5	15-20	6.3	0.0	1.2	0.8	0.0	0.0
Penoxsulam	25	15-20	0.0	0.0	1.0	0.7	0.0	0.0
Penoxsulam (check)	22.5	8-12	9.9	0.0	1.4	0.8	0.0	0.0
Bispyribac-sodium	20	10-14	14.5	13.7	3.3	2.5	0.4	0.0
Bispyribac-sodium	25	15-25	-	0.0	-	2.1	-	0.0
Butachlor	1500	0-3	0.0	0.0	0.3	0.0	0.0	0.0
Weed free			0.0	0.0	0.0	0.0	0.0	0.0
Weedy check			223.7	232.1	5.9	3.8	17.7	1.2
LSD (p=0.05)			14.4	11.6	1.3	0.7	4.0	0.6

Table 3. Effect of penoxsulam 2.5% ODon plant height, yield attributes and grain yield of transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Time (DAT)	Plant height (cm)		No. of effective tillers/ mrl		Panicle length (cm)		Grain yield (t/ha)	
			2011	2012	2011	2012	2011	2012	2011	2012
Penoxsulam	20	15-20	92.5	121.3	53.2	76.5	20.2	22.1	5.17	6.48
Penoxsulam	22.5	15-20	92.2	120.7	57.5	82.7	20.3	22.1	5.68	6.89
Penoxsulam	25	15-20	91.7	121.1	56.5	81.2	20.0	21.5	5.59	6.77
Penoxsulam (check)	22.5	8-12	93.5	120.5	56.7	82.2	20.1	22.0	5.54	6.84
Bispyribac-sodium	20	10-14	93.1	121.0	54.2	77.2	20.2	21.8	5.39	6.56
Bispyribac-sodium	25	15-25	-	121.3	-	78.8	-	21.7	-	6.65
Butachlor	1500	0-3	90.9	122.1	58.8	85.5	20.3	22.1	5.57	7.12
Weed free			95.1	121.1	60.8	83.3	20.3	22.0	5.90	6.98
Weedy check			93.1	121.5	39.8	50.5	20.0	21.2	3.68	3.95
LSD (p=0.05)			NS	NS	5.4	5.5	NS	NS	0.44	0.40

Table 4. Effect of penoxsulam on economics of transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Time (DAT)	Variable cost (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B-C ratio	
			2011	2012	2011	2012	2011	2012	2011	2012
Penoxsulam	20	15-20	30.93	32.66	57.38	82.92	26.44	50.25	1.85	2.54
Penoxsulam	22.5	15-20	31.14	32.87	63.06	88.24	31.92	55.37	2.03	2.68
Penoxsulam	25	15-20	31.34	33.08	62.05	86.66	30.70	53.58	1.98	2.62
Penoxsulam (check)	22.5	8-12	30.83	32.56	61.53	87.60	30.70	55.04	2.00	2.69
Bispyribac-sodium	20	10-14	30.52	32.25	59.88	84.03	29.37	51.78	1.96	2.61
Bispyribac-sodium	25	15-25	-	32.56	-	85.18	-	52.62	-	2.62
Butachlor	1500	0-3	29.79	31.50	61.88	91.08	32.09	59.58	2.08	2.89
Weed free			37.44	40.26	65.45	89.39	28.00	49.13	1.75	2.22
Weedy check			28.85	30.53	40.89	50.60	12.04	20.07	1.42	1.66

Table 5. Performance of penoxsulam 2.5% OD against weeds in transplanted rice in adaptive trials at farmers' fields (*Kharif* 2017)

District	Location	Variety	Weed control (%)		Grain yield (t/ha)	
			Penoxsulam (22.5 g/ha)	Bispyribac-Na (25 g/ha)	Penoxsulam (22.5 g/ha)	Bispyribac-Na (25 g/ha)
Karnal	Uchana-1	*CSR-30*	90	89	3.26	2.97
Karnal	Uchana-2	*CSR-30*	92	91	3.10	3.06
Karnal	Tikri	*HKR 47*	92	90	6.30	6.12
Karnal	Shindarpur	*PB 1121*	90	92	3.45	3.52
Karnal	Uchani-1	*PB 1121*	95	90	3.85	3.50
Karnal	Uchani-2	*CSR -30*	89	87	2.85	2.56
Karnal	Popra	*PB 1121*	92	90	3.82	3.62
Karnal	Kunjpura	*PB 1121*	95	92	3.94	3.71
Karnal	Panhari	*HKR 47*	95	93	6.64	6.30
Kuruksetra	Darala	*CSR-30*	90	88	3.02	2.94
Panipat	Ishrana	*PB 1121*	90	87	3.42	3.25
Panipat	Dhurana	*PB 1121*	88	85	3.55	3.28
Average	-	-	91.5	89.5	3.93	3.74

B-C ratio from penoxsulam 22.5 g/ha (2.03-2.68) was also almost similar to penoxsulam 24% SC 22.5 g/ha (**Table 4**).

Herbicide residues and crop phyto-toxicity: There was no phyto-toxicity of applied penoxsulam 2.5% OD even up to 50 g/ha on transplanted rice crop at 1, 3, 5, 7, 10, 15 and 30 days after application (DAA) of the herbicide during *Kharif* 2011 to 2013 (data not given). Also there was no residual phyto-toxicity of penoxsulam up to 50 g/ha on succeeding wheat crop during *Rabi* 2011-12 to 2013-14. No residues of penoxsulam applied at 22.5 g/ha and 45.0 g/ha were detected in soil, straw and grains of rice at harvest during *Kharif* 2017 (data not given), indicating its safety to the human/animal health and the environment.

On-farm adaptive trials

Penoxsulam at 22.5 g/ha applied at 15-20 DAT in transplanted rice (scented rice varieties '*CSR 30*' at four locations and PB 1121 at six locations) and coarse rice '*HKR 47*' at two locations) during *Kharif* 2017 provided 88-95% control of weeds (**Table 5**). The average grain yield obtained under penoxsulam 22.5 g/ha (3.93 t/ha) was 5.1% higher as compared to the check herbicide bispyribac-sodium 25 g/ha (3.74 t/ha).

The present investigation indicated that foliar application of penoxsulam 2.5% OD at 22.5 g/ha as PoE (15-20 DAT) could be a better alternative for satisfactory control of complex weed flora and yield improvement in transplanted rice without causing any phyto-toxicity up to 50 g/ha on rice and succeeding wheat crop. It also did not leave any detectable residual carry-over effects in soil, straw and rice grain up to 45 g/ha. Wider window of its application over penoxsulam offers more convenient option to farmers for control of broad spectrum of weeds in transplanted rice.

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Effect of crop intensification and establishment techniques on weed infestation under different cropping system

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ABSTRACT

The field experiment was conducted during 2015-16 and 2016-17 at Norman E. Borlaug Crop Research Center, Pantnagar G.B Pant University of Agriculture & Technology, Pantnagar, U.S. Nagar (Uttarakhand) India, to study the crop intensification and establishment techniques influence on weed management under irrigated rice-wheat system. The experiment was laid out in a randomized block design with nine treatments and replicated thrice. The nine cropping sequence were evaluated for productivity. Density of these weeds was significantly affected by crop intensification and establishment techniques during both the years. In *Kharif* season, total weed density was recorded significantly lower in treatment rice (TPR) – wheat while the highest total weed density was recorded in rice (DSR) –vegetable pea – maize grain treatment during both the years. Weed density as affected by crop rotations maize (B) (cob + fodder) + cowpea (B) + *sesbania* (F)-2:1:2 - vegetable pea (B) + toria (F)-3:1 – groundnut (B) + mentha was found to be the the superior in terms of weed suppression.

INTRODUCTION

Weeds are an important constraint in agricultural production systems, acting at same tropic level as the crop; weeds capture a part of the available resources that are essential for plant growth (Oerke 2006). Effective weed management is critical to maintaining agricultural productivity. Inevitably, leaving weeds uncontrolled will sooner or later lead to considerable reductions in crop yield and increase production cost. Manual weed control is labour intensive and therefore limits the production area. Crop rotations affect seed banks because weed control measures change with successive crops (Ball 1992). Weeds that survive and produce seeds in one crop contribute to the seed bank from which weed seedlings are recruited in successive crops. Because of greater variability in the type and timing of soil, crop, and weed management practices, there are more opportunities for weed mortality events in rotations than in monoculture (Martin and Felton 1993). Manipulation of cropping systems for the purpose of improving integrated weed management requires a good understanding of weed dynamics and influences of crop- and soil-related factors on weed life cycles. Changes in crop rotation and herbicide use could change the weed seed banks in arable soils (Squire *et al.* 2000). Rotations comprised of two cool-season crops followed by two warm-season crops are the most disruptive of weed population growth. The impact of rotation design on weed community density is enhanced by no-till.

MATERIALS AND METHODS

A field experiment was conducted during 2015-16 and 2016-17 at Norman E. Borlaug Crop Research Center, G.B Pant University of Agriculture & Technology, Pantnagar, U.S. Nagar (Uttarakhand) India, to study crop intensification and establishment techniques to enhance productivity under irrigated rice-wheat system. The soil of experimental field was loam in texture. The soil of experimental field was high in organic carbon (0.80), low in available nitrogen (260.4 kg/ha), high in phosphorus (29.6 kg/ha) and medium in potassium (203.9 kg/ha) with neutral in pH 7.33. The experiment was laid out in a randomized block design with nine treatments [rice (transplanted rice) – wheat], [rice (transplanted rice) - vegetable pea – groundnut], [rice (direct seeded rice) - vegetable pea - maize (grain)], [rice (direct seeded rice) - potato -cowpea (vegetable +fodder)], [rice (direct seeded rice) - vegetable pea - maize (cob + fodder)], [rice (direct seeded rice) - yellow sarson – cowpea], [rice (direct seeded rice) (bed) + sesbania (furrow)- 2:1-vegetable pea (bed) + toria (furrow)- 2:1 - maize (bed) (cob + fodder) + mentha (furrow)1:1, (furrow irrigated raised bed, 45cm x 30 cm)], [soybean (bed) + rice (direct seeded rice) (furrow)-2:1 - wheat + mentha (3:1) – continue same cropping system (narrow bed system, 60 cm x 30 cm)], [maize (bed) (cob + fodder) + cowpea (vegetable) (bed) + sesbania (furrow)-2:1:2 - vegetable pea + toria-3:1 – groundnut + mentha-3:1 (broad bed furrow 105 cm x 30 cm)] and replicated thrice. The crops were sown as per the package of practices recommended for different crops. The nine cropping sequence were evaluated for productivity. '*HKR-47*' variety of rice, '*UP-2572*' variety of wheat, '*Kashi kanchan*' variety of cowpea, '*Suvarna*' variety of maize (cob + fodder), '*Arkle*' variety of vegetable pea, '*Uttara*' variety of toria, '*Kufri Bahar (3797)*' variety of potato, '*PS-1024*' variety of soybean, '*PPS-1* 'variety of yellow mustard, '*ICGS-11*' variety of groundnut and '*Kosi*' variety of mentha were used in experimentation.

Weed density/ m^2 recorded just before the execution of first hand weeding or before the application of post emergence herbicides during both years by using a quadrate of size 0.5 m x 0.5 m (0.25 m^2) and expressed as number per meter square. Weed dry matter of all the weed species (grasses, broad leaved weeds and sedges) recorded just before the execution of firsthand weeding or before application of post emergence herbicides within an area of quadrate of 0.5 m x 0.5 m (0.25 m^2) were cut closed to ground surface, separated species wise and sun dried for first 4-5 days thereafter placed into an oven at 70 $\pm$ 1 ^{O}C temperatures till a constant weight was obtained. The dry weight of weeds was expressed as g/ m^2. Total weed dry matter was worked out by adding of all weed species.

RESULTS AND DISCUSSION

Weed density in *Kharif*

The data on density of grasses, broad leaved weeds, sedges and total weeds during *Kharif*season in 2015 and 2016 is presented in **Table 1**. Density of these weeds was significantly affected by crop intensification and establishment techniques during both the years.

In *Kharif* season, total weed density was recorded significantly lower in treatment rice (TPR) – wheat while the highest total weed density was recorded in rice (DSR) –vegetable pea – maize grain treatment during both the years. The total density of grasses in *Kharif* was recorded significantly lower in

Table 1. Effect of crop intensification and establishment techniques on total weed density during *Kharif*

Treatment	Total weeds in *Kharif* (no./m^2)							
	Grassy weeds		BLWs		Sedges		Total weeds	
	2015	2016	2015	2016	2015	2016	2015	2016
Rice (TPR) – wheat	5.7 (32.0)	6.4 (40.0)	3.7 (13.3)	4.2 (17.3)	10.0 (98.7)	10.2 (104.0)	12.0 (144.0)	12.7 (161.3)
Rice (TPR) - vegetable pea – groundnut	6.4 (40.0)	6.9 (48.0)	4.7 (21.3)	5.3 (28.0)	10.1 (102.7)	10.3 (105.3)	12.8 (164.0)	13.5 (181.3)
Rice (DSR) –vegetable pea – maize grain	10.1 (102.7)	10.5 (109.3)	9.7 (94.7)	10.5 (109.3)	11.6 (133.3)	11.9 (141.3)	18.2 (330.7)	19.0 (360.0)
Rice (DSR) - potato -cowpea (vegetable)	9.0 (80.0)	9.6 (92.0)	9.3 (85.3)	10.1 (102.7)	11.4 (129.3)	11.6 (134.7)	17.2 (294.7)	18.2 (329.3)
Rice (DSR) - vegetable pea - maize (cob + fodder)	9.7 (93.3)	10.3 (106.7)	9.3 (86.7)	10.0 (100.0)	11.3 (128.0)	11.6 (133.3)	17.6 (308.0)	18.4 (340.0)
Rice (DSR) - yellow sarson – cowpea (vegetable + green manure)	9.2 (84.0)	9.9 (97.3)	9.7 (94.7)	9.9 (97.3)	11.4 (129.3)	11.5 (132.0)	17.6 (308.0)	18.1 (326.7)
Rice (DSR) (B)+ sesbania (F)- 2:1 (FIRBS 45 x 30 cm)-vegetable pea (B) + Toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1 (FIRBS)	8.3 (68.0)	8.6 (73.3)	8.5 (72.0)	8.7 (76.0)	10.7 (114.7)	10.9 (118.7)	16.0 (254.7)	16.4 (268.0)
Soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm	8.8 (77.3)	9.1 (82.7)	8.7 (76.0)	9.0 (81.3)	10.6 (112.0)	11.2 (124.0)	16.3 (265.3)	17.0 (288.0)
Maize (B) (cob + fodder) + cowpea (B) + sesbania (F)- 2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria- 3:1 (BBF) – groundnut+mentha-3:1 (BBF)	9.5 (89.3)	9.9 (97.0)	8.4 (70.7)	8.3 (69.0)	10.3 (106.7)	10.7 (113.3)	16.3 (266.7)	16.7 (279.3)
LSD (p=0.05)	0.49	0.47	0.41	0.48	0.61	0.65	0.46	0.64

Original values given in parentheses was subjected to square root ($\sqrt{x+1}$)transformation before analysis; BLWs =broad-leaved weeds rice (TPR) – wheat system (5.68 and 6.36 no. /m²) treatment during 2015 and 2016 while the highest was in rice (DSR) –vegetable pea – maize grain treatment system. Direct-seeded rice faces a potential threat from changes in the competing weed flora and with an increase in those species that are difficult to control (Johnson *et al.* 2003). These include *I. rugosum, E. crus-galli, E. colona, L. chinensis* and *Cyperus* spp. The total density of broad-leaved weeds in *kharif* during both the years was recorded significantly lower in rice (TPR) – wheat treatment while the maximum density of these weeds was recorded in rice (DSR) –vegetable pea – maize grain treatment. The total density of sedges in *Kharif* was found significantly lower in rice (TPR) – wheat treatment while highest in rice (DSR) –vegetable pea – maize grain treatment during both the years. Malik and Yadav (2008) also reported that integrated weed management, sowing sesbania with the rice and use of a selective herbicide at 30–40 days after sowing to kill the sesbania to provide mulch, which reduced the need for hand weeding.

Weed density in *Rabi*

The observation recorded to density of grasses, broad leaved weeds, sedges and total weeds during *Rabi* season in 2015-16 and 2016-17 under different treatment are presented in **Table 2.** Density of these weeds was significantly affected by crop intensification and establishment techniques during both the years.

In *Rabi* season, total weed density was found to be significantly influenced due to different treatments during both the years. The lowest total weed density in *Rabi* season was recorded in maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1 (BBF) treatment while the highest value in rice (TPR) – wheat treatment during 2015-16 and 2016-17, respectively. No density of grasses in *Rabi* season was recorded in rice (TPR) - vegetable pea – groundnut, rice (DSR) –vegetable pea – maize grain, rice (DSR) - vegetable pea - maize (cob + fodder), rice (DSR) - yellow sarson – cowpea (vegetable + green manure), rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm) - vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + menthe (F) 1:1 (FIRBS), maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) – vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1 (BBF) treatment while the highest density was recorded in rice (TPR) – wheat during 2015-16 and 2016-17, respectively. The total

Table 2. Effect of crop intensification and establishment techniques on total weed density during *Rabi*

Treatment	Total weeds in *Rabi* (no./m²)							
	Grassy weeds		BLWs		Sedges		Total weeds	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Rice (TPR) – wheat	6.04 (36.0)	6.26 (38.7)	10.85 (117.3)	11.45 (130.7)	7.15 (50.7)	7.43 (54.7)	14.30 (204.0)	14.98 (224.0)
Rice (TPR) - vegetable pea – groundnut	0.71 (0)	0.71 (0)	9.62 (92.0)	9.96 (98.7)	6.67 (44.0)	6.77 (45.3)	11.68 (136.0)	12.02 (144.0)
Rice (DSR) –vegetable pea – maize grain	0.71 (0)	0.71 (0)	11.74 (137.3)	12.18 (148.0)	6.24 (38.7)	6.52 (42.0)	13.28 (176.0)	13.8 (190.0)
Rice (DSR) - potato -cowpea (vegetable)	1.34 (1.3)	0.71 (0)	11.33 (128.0)	11.57 (133.3)	6.04 (36.0)	6.14 (37.3)	12.87 (165.3)	13.08 (170.7)
Rice (DSR) - vegetable pea - maize (cob + fodder)	0.71 (0)	0.71 (0)	10.97 (120.0)	11.32 (127.7)	6.14 (37.3)	6.25 (38.7)	12.56 (157.3)	12.91 (166.3)
Rice (DSR) - yellow sarson – cowpea (vegetable + green manure)	0.71 (0)	0.71 (0)	8.19 (66.7)	8.67 (74.7)	5.33 (28.0)	5.69 (32.0)	9.75 (94.7)	10.35 (106.7)
Rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm)-vegetable pea (B) + Toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder)+ mentha (F)1:1 (FIRBS)	0.71 (0)	0.71 (0)	5.82 (33.3)	6.67 (44.0)	4.67 (21.3)	5.20 (26.7)	7.43 (54.7)	8.43 (70.7)
Soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm	4.93 (24.0)	5.08 (25.3)	7.95 (62.7)	8.35 (69.3)	4.95 (24.0)	5.08 (25.3)	10.54 (110.7)	10.97 (120.0)
Maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + Toria-3:1 (BBF) – groundnut+mentha-3:1 (BBF)	0.71 (0)	0.71 (0)	5.92 (34.7)	6.45 (41.3)	4.38 (18.7)	4.52 (20.0)	7.33 (53.3)	7.85 (61.3)
LSD (p=0.05)	0.35	0.19	0.37	0.47	0.62	0.55	0.50	0.60

Original values given in parentheses was subjected to square root $(\sqrt{x+1})$transformation before analysis; BLWs =broad-leaved weeds density of broad-leaved weeds in *Rabi* was recorded significantly lower in rice (DSR) (B) + sesbania (F)-2:1 (FIRBS 45 x 30 cm)-vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F) 1:1 (FIRBS) treatment during 2015-16 and maize (B) (cob + fodder)+ cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) treatment during 2016-17, respectively. The total density of sedges in *Rabi* season was recorded significantly lower in maize (B) (cob + fodder)+ cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) treatment while the highest density was recorded in rice (TPR) – wheat treatment, during 2015-16 and 2016-17, respectively which might be due to direct-seeding of rice. Similarly weed suppression is a desirable trait of a cover crop and in general, cover cropping systems have large potentials for weed management in agro ecosystems (Mohammadi 2013).

Weed density in summer

The mean values for density of grasses, broad leaved weeds, sedges and total weeds during summer season in 2015 and 2016 under different treatment are presented in **Table 3**. Density of these weeds was significantly affected by crop intensification and establishment techniques during both the years.

Total weed density in summer season was significantly influenced due to various treatments during both the years. No population of grasses, broad-leaved weeds and sedges in summer was recorded in soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm treatment. The highest total density of weeds was recorded in rice (DSR) - vegetable pea - maize (cob + fodder) treatment during 2015 and 2016. The total weed density of grasses, broad-leaved weeds and sedges in summer season during both the years was recorded significantly higher in rice (DSR) - vegetable pea - maize (cob + fodder) treatment. Similarly, the cover crop within cropping systems was found to suppress weed emergence or without adversely affecting crops growth (Norsworthy 2003).

Total weed density in system

The mean values for density of total grasses, broad-leaved weeds, sedges and total weeds during *Rabi* season in 2015-16 and 2016-17 under different treatment are presented in **Figure 1**. Density of these weeds was significantly affected by crop intensification and establishment techniques during both the years.

Total weed density of system was recorded significantly lower in maize (B) (cob + fodder) +

Table 3. Effect of crop intensification and establishment techniques on total weed density during summer season

Treatment	Total weeds in summer (no./m^2)							
	Grassy weeds		BLWs		Sedges		Total weeds	
	2015	2016	2015	2016	2015	2016	2015	2016
Rice (TPR) – wheat	-	-	-	-	-	-	-	-
Rice (TPR) - vegetable pea – groundnut	10.3 (105.3)	10.5 (109.3)	9.7 (94.7)	10.1 (101.3)	8.7 (76.0)	9.3 (86.7)	16.6 (276.0)	17.2 (297.3)
Rice (DSR) –vegetable pea – maize grain	10.7 (113.3)	10.8 (117.3)	10.0 (98.7)	10.1 (102.7)	11.7 (140.0)	12.0 (144.0)	18.7 (352.0)	19.1 (364.0)
Rice (DSR) - potato - cowpea (vegetable)	10.5 (110.7)	11.0 (120.0)	8.7 (74.7)	9.3 (86.7)	10.4 (108.0)	11.0 (121.3)	17.1 (293.3)	18.1 (328.0)
Rice (DSR) - vegetable pea - maize (cob + fodder)	10.7 (113.3)	11.2 (125.3)	10.3 (106.7)	10.8 (117.3)	12.2 (149.3)	12.4 (154.7)	19.2 (369.3)	19.9 (397.3)
Rice (DSR) - yellow sarson – cowpea (vegetable + green manure)	10.6 (112.0)	11.0 (121.3)	10.0 (100.0)	10.5 (109.3)	11.2 (124.0)	11.4 (129.3)	18.3 (336.0)	19.0 (360.0)
Rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm)-vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1 (FIRBS)	9.6 (92.0)	10.1 (101.3)	9.0 (80.0)	9.5 (90.7)	8.7 (76.0)	9.2 (85.3)	15.8 (248.0)	16.6 (277.3)
Soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)	0.7 (0)
Maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1 (BBF)	8.7 (76.0)	9.3 (86.7)	8.0 (64.0)	8.5 (72.0)	6.0 (36.0)	6.4 (41.3)	13.3 (176.0)	14.1 (200.0)
LSD (p=0.05)	0.37	0.98	0.44	0.79	1.41	0.82	0.84	1.18

Original values given in parentheses was subjected to square root ($\sqrt{x+1}$)transformation before analysis; BLWs =broad-leaved weeds

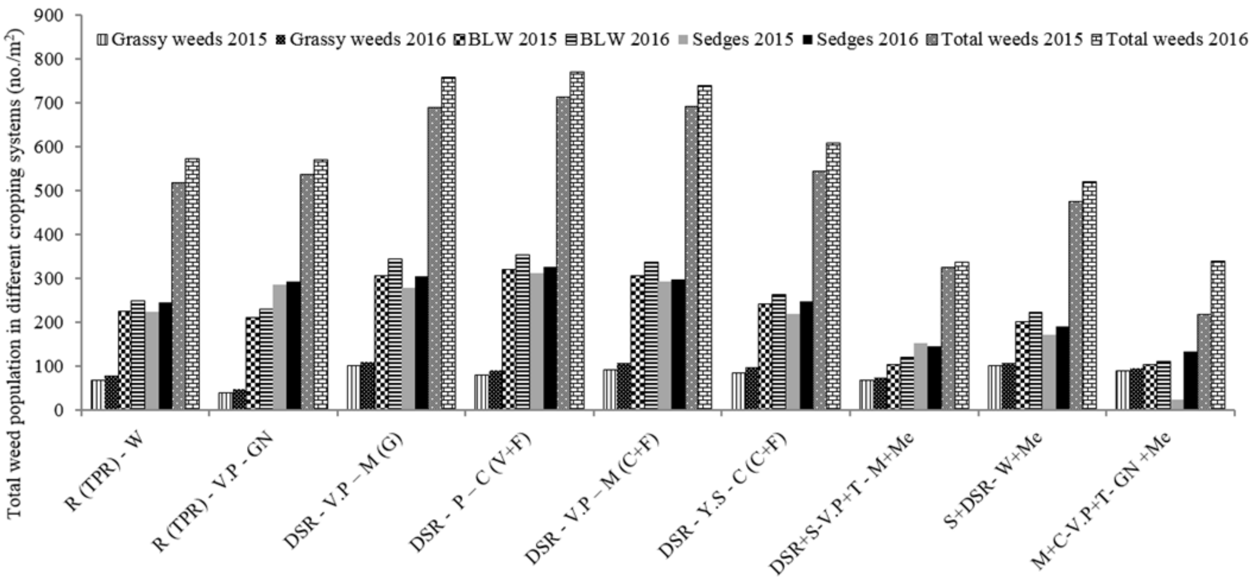

Figure 1. Effect of crop intensification and establishment techniques on weed density of total cropping systems

cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) treatment while the highest was recorded in rice (DSR) - potato -cowpea (vegetable) during both the years, respectively. The total density of grasses was recorded significantly lower in rice (TPR) - vegetable pea – groundnut treatment while the highest was recorded in rice (DSR) – vegetable pea – maize grain treatment during both the years, respectively. The total density of broad-leaved weeds recorded during 2015-16 and 2016-17 was found to be significantly lower in maize (B) (cob + fodder) + cowpea (B) + sesbania (F) -2:1:1(BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) - groundnut+mentha-3:1(BBF) treatment while the highest density in rice (DSR) - potato -cowpea (vegetable) treatment, during both years. The total population of sedges in summer was recorded significantly lower in maize (B) (cob + fodder) cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) treatment while the highest was recorded in rice (DSR) - potato -cowpea (vegetable) treatment during both the years. The lowest weed density in maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) treatment could be due to inclusion of different crops, *viz*. legumes, oilseeds, vegetables and fodder in cropping sequence. Similarly, Liebman and Gallandt (1997) also reported that crop rotation affects weed demography and subsequent population dynamics and hence it is considered to be a vital tool of weed management. Combinations of 25 cropping sequence reduced weed density compared to monoculture (Liebman and Ohno (1998). Mandal and Hossain (2015) observed different density of different weeds in different cropping system in winter and pre-*Kharif* seasons, maximum and minimum densities of *Digitaria sanguinalis* and *Echinochloa colona* were recorded in most of the crops.

Weed dry matter

Weeds dry matter in *Kharif, Rabi* and summer

The mean values for dry matter of total grasses, broad leaved weeds, sedges and total weeds during *Kharif, Rabi* and summer season in 2015-16 and 2016-17 under different treatment are presented in **Table 4**. Density of these weeds was significantly affected by crop intensification and establishment techniques during both the years.

In *Kharif*, dry matter accumulation of grassy, BLWs and sedges in *Kharif* was influenced significantly due to different treatments during 2015 and 2016. Significantly lower weed dry matter of grasses was recorded in rice (TPR) – wheat treatment while the highest dry matter was recorded in rice (DSR) - vegetable pea - maize (cob + fodder) treatment during 2015 and 2016, respectively. The lowest dry matter accumulation of BLWs was recorded in rice (TPR) – wheat while the highest dry matter was recorded in rice (DSR) - yellow sarson – cowpea (vegetable + green manure) during 2015 and in rice (DSR) - vegetable pea - maize (cob + fodder) during 2016, respectively. Dry matter accumulation of sedges was recorded significantly higher in rice (TPR) – wheat treatment while the highest dry matter was recorded in rice (DSR) –vegetable pea – maize grain treatment during 2015 and 2016, respectively. This might be due to direct seeding rice.

In *Rabi*, dry matter accumulation of grassy, BLWs and sedges was significantly influenced due to different treatments during 2015-16 and 2016-17, respectively. No weed dry matter of grasses was recorded in rice (TPR) - vegetable pea – groundnut, rice (DSR) –vegetable pea – maize grain, rice (DSR) - potato -cowpea (vegetable), rice (DSR) - vegetable pea - maize (cob + fodder), rice (DSR) - yellow sarson – cowpea (vegetable + green manure), rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm) -

Table 4. Effect of crop intensification and establishment techniques on weed dry matter in *Kharif*, *Rabi* and summer season

Treatment	Weed dry matter (g/m^2)					
	Grassy weed		BLWs		Sedges	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Kharif						
Rice (TPR) – wheat	2.82(7.5)	2.92(8.0)	3.03(8.7)	3.13(9.3)	3.52(11.9)	3.60(12.5)
Rice (TPR) - vegetable pea – groundnut	2.98(8.4)	3.08(9.0)	3.29(10.3)	3.42(11.2)	3.63(12.7)	3.78(13.8)
Rice (DSR) –vegetable pea – maize grain	3.93(15.0)	4.03(15.7)	4.21(17.2)	4.31(18.1)	3.97(15.3)	4.17(16.9)
Rice (DSR) - potato - cowpea (vegetable)	3.59(12.4)	3.72(13.4)	4.11(16.4)	4.33(18.2)	3.96(15.2)	4.09(16.3)
Rice (DSR) - vegetable pea - maize (cob + fodder)	3.96(15.2)	4.11(16.4)	4.20(17.2)	4.36(18.5)	3.97(15.3)	4.05(15.9)
Rice (DSR) - yellow sarson – cowpea (vegetable + green manure)	3.78(13.8)	3.89(14.6)	4.25(17.6)	4.30(18.0)	3.91(14.8)	4.04(15.8)
Rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm)- vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1 (FIRBS)	3.38(10.9)	3.61(12.5)	3.82(14.1)	4.00(15.5)	3.77(13.7)	3.89(14.7)
Soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm	3.53(12.0)	3.6(12.4)	3.87(14.5)	3.97(15.3)	3.89(14.6)	3.94(15.0)
Maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1 (BBF)	3.18(9.6)	3.36(10.8)	3.69(13.1)	3.76(13.6)	3.77(13.7)	3.85(14.4)
LSD (p=0.05)	0.13	0.23	0.20	0.18	0.26	0.21
Rabi						
Rice (TPR) – wheat	2.68(6.7)	2.91(7.9)	4.93(23.9)	5.19(26.5)	3.51(11.8)	3.54(12.1)
Rice (TPR) - vegetable pea – groundnut	0.71(0)	0.71(0)	4.28(17.8)	4.51(19.8)	3.24(10.0)	3.39(11.0)
Rice (DSR) –vegetable pea – maize grain	0.71(0)	0.71(0)	4.81(22.7)	5.02(24.7)	3.18(9.6)	3.20(9.7)
Rice (DSR) - potato - cowpea (vegetable)	0.77(0.1)	0.71(0)	4.90(23.5)	4.99(24.4)	3.05(8.8)	3.08(9.0)
Rice (DSR) - vegetable pea - maize (cob + fodder)	0.71(0)	0.71(0)	5.10(25.5)	5.31(27.7)	3.09(9.1)	3.24(10.0)
Rice (DSR) - yellow sarson – cowpea (vegetable + green manure)	0.71(0)	0.71(0)	4.06(16.0)	4.26(17.6)	2.73(7.0)	2.80(7.3)
Rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm)- vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1 (FIRBS)	0.71(0)	0.71(0)	2.58(6.2)	2.85(7.6)	2.65(6.5)	2.72(6.9)
Soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm	2.51(5.8)	2.65(6.5)	2.86(7.7)	2.90(7.9)	2.67(6.7)	2.75(7.1)
Maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1 (BBF)	0.71(0)	0.71(0)	2.43(5.4)	2.66(6.6)	2.47(5.6)	2.65(6.5)
LSD (p=0.05)	0.14	0.04	0.28	0.22	0.30	0.23
Summer						
Rice (TPR) – wheat	-	-	-	-	-	-
Rice (TPR) - vegetable pea – groundnut	3.55(12.1)	3.62(12.6)	3.93(15.0)	4.02(15.6)	3.04(8.8)	3.12(9.3)
Rice (DSR) – vegetable pea – maize grain	3.69(13.1)	3.78(13.8)	3.97(15.2)	4.04(15.8)	3.72(13.3)	3.60(12.4)
Rice (DSR) - potato - cowpea (vegetable)	3.64(12.8)	3.69(13.1)	3.80(13.9)	3.71(13.2)	3.35(10.7)	3.91(14.8)
Rice (DSR) - vegetable pea - maize (cob + fodder)	3.65(12.8)	3.75(13.5)	4.31(18.1)	4.43(19.2)	3.77(13.7)	3.88(14.6)
Rice (DSR) - yellow sarson – cowpea (vegetable + green manure)	3.63(12.7)	3.78(13.8)	4.00(15.5)	4.13(16.6)	3.47(11.5)	3.59(12.4)
Rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm)- vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1 (FIRBS)	3.44(11.3)	3.54(12.0)	3.71(13.3)	3.77(13.7)	3.02(8.6)	3.12(9.2)
Soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)
Maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1 (BBF)	3.25(10.1)	3.36(10.8)	3.55(12.1)	3.57(12.3)	2.46(5.6)	2.62(6.4)
LSD (p=0.05)	0.48	0.46	0.37	0.50	0.25	0.47

Original values given in parentheses was subjected to square root $(\sqrt{x+1})$transformation before analysis; BLWs =broad-leaved weeds vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F) 1:1(FIRBS), and maize (B) (cob + fodder)+ cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) while the highest dry matter was recorded in rice (TPR) – wheat treatment during 2015-16 and 2016-17, respectively. Significantly lower weed dry matter was recorded in maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) during 2015-16 and maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) during 2016-17 while the highest dry matter accumulation was recorded in rice (TPR) – wheat during 2015-16 and rice (DSR) - vegetable pea - maize (cob + fodder) during 2016-17, respectively. The lowest dry matter accumulation of sedges was recorded in maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha-3:1(BBF) treatment while significantly higher dry matter was recorded in rice (TPR) – wheat treatment during 2015-16 and 2016-17, respectively.

In summer, dry matter accumulation of grassy, BLWs and sedges was significantly influenced due to different treatments during 2015 and 2016, respectively. Significantly lower dry matter accumulation of grassy, BLWs and sedges was recorded in maize (B) (cob + fodder) + cowpea (B) + sesbania (F) -2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) – groundnut + mentha -3:1(BBF) treatment during summer season. The highest dry matter of grasses was recorded in rice (DSR) – vegetable pea – maize grain treatment during 2015 and rice (DSR) –vegetable pea – maize grain and rice (DSR) - yellow sarson – cowpea (vegetable + green manure) treatments during 2016. rice (DSR) - vegetable pea - maize (cob + fodder) treatment recorded the highest values of dry matter accumulation of BLWs during both years and sedges during 2015 while the highest dry matter accumulation in sedges during 2016 was found in rice (DSR) - potato -cowpea (vegetable) treatment.

Total weeds dry matter in system

The data regarding to total dry matter of grassy, BLWs and sedges weeds in the system during 2015-16 and 2016-17 under different treatment are presented in (**Figure 2**). Density of these total weeds was significantly affected by crop intensification and establishment techniques during both the years.

Total dry matter was recorded significantly lower in soybean (B)+rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm treatment while the highest dry matter was recorded in rice (DSR) - vegetable pea - maize (cob + fodder) treatment during 2015-16 and 2016-17, respectively. Significantly lower dry matter accumulation of grassy weeds was recorded in rice (TPR) – wheat treatment whereas the highest dry matter was recorded in rice (DSR) – vegetable pea – maize grain during 2015-16 and rice (DSR) - vegetable pea - maize (cob + fodder) during 2016-17, respectively. The lowest total dry matter

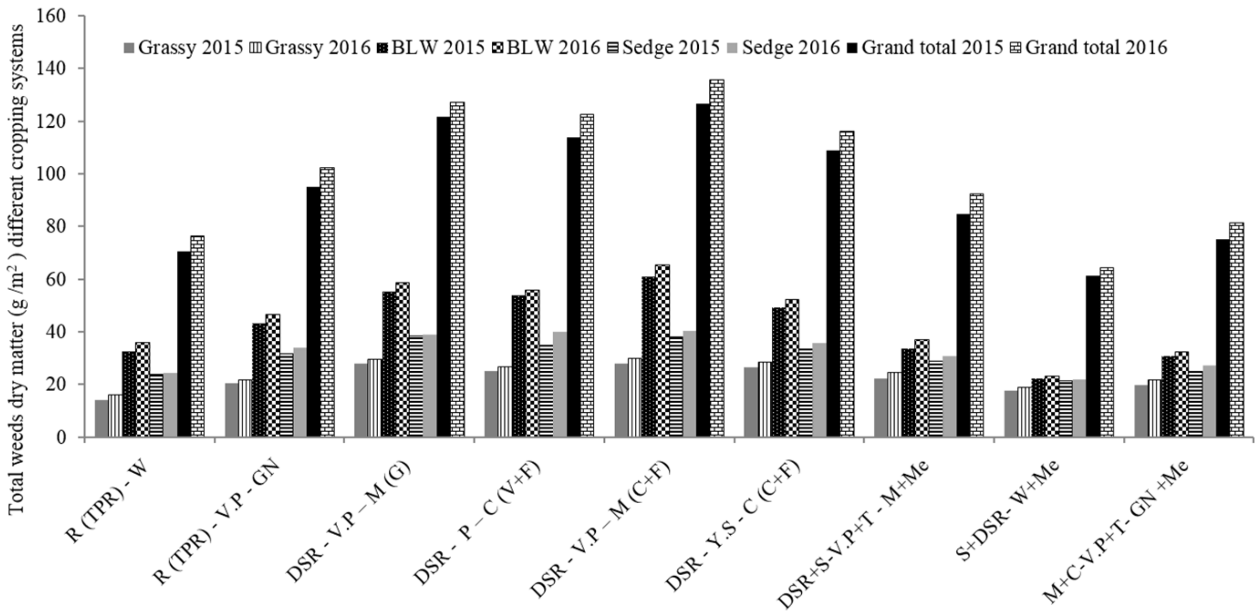

Figure 2. Effect of crop intensification and establishment techniques on total weed dry matter in cropping systems

accumulation of BLWs was recorded in soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm while the highest total dry matter was recorded in rice (DSR) - vegetable pea - maize (cob + fodder) during 2015-16 and 2016-17, respectively. Significantly lower dry matter accumulation of sedges was recorded in soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm) during both years while the highest dry matter was recorded in rice (DSR) – vegetable pea – maize grain during 2015-16 and rice (DSR) - vegetable pea - maize (cob + fodder) during 2016-17, respectively. It might be due to inter-cropping effect. Inter-cropping can reduce both weed density and biomass to a great extent due to decreased light transmission through the canopy (Baumann *et al.* 2000). Inter-cropping with *Sesbania* for 30 days were found effective in controlling weeds in DSR (Singh *et al.* 2007).

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Effect of tillage and weed control in direct-seeded rice-wheat cropping system

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ABSTRACT

The present experiment was carried out in a split-plot design with four tillage practices in the main plot and three methods of weed control practices in sub plot with four replications at agronomical research farm of Birsa Agricultural University, Ranchi during 2009-10 to 2010-11 to find out the effective tillage methods adopted in direct-seeded rice and wheat with different weed control methods. Results revealed that in direct-seeded rice density of grassy, broad-leaved weeds and sedges accounted for 23.1, 59.2 and 17.7% and in wheat, grassy and broad-leaved weeds accounted for 5.7 and 94.3% respectively of total weed density. Conventional tilled plots had more number of weeds per unit area as compared to zero tilled. Conventional tilled both rice and wheat produced 25.3, 11.9 and 11.4% higher mean rice equivalent yield compare to mean yield due to other tillage combination. Two hand weeding (20 and 40 DAS for rice and 25 and 50 DAS for wheat) and application of recommended herbicides being at par gave higher rice equivalent yield than weedy check.

INTRODUCTION

Rice (*Oryza sativa* L.) is grown in different ecosystems and physical condition of the soil. Cultivation of rice by transplanting in rice-wheat cropping system is most popular in northern India, but it is highly labour intensive and expensive method of cultivation for marginal farmers which account for 65% of total farmers. This method requires a large quantity of water for puddling, transplanting and establishment of rice seedlings. Direct-seeding eliminates the need of raising, maintaining and subsequent transplanting of seedlings, besides, it is cost effective can save water through earlier rice crop establishment and allows timely sowing of wheat (Singh *et al.* 2007). However direct-seeding is subjected to greater weed competition than transplanted rice (Rao *et al.* 2007). Similarly, loss in grain yield of wheat due to weeds was reported to be 65–90% (Jain *et al.* 2006). Hence, the present investigation was undertaken to study the impact of combinations of conventional and zero tillage in rice and wheat crops and weed control methods on weed dynamics and productivity of rice-wheat system.

MATERIALS AND METHODS

A field experiments were conducted in a split-plot design at agronomical research farm of Birsa Agricultural University, Ranchi during the rainy and winter season of 2009-10 and 2010-11. The treatment consisted of combination of four tillage practices, *viz.* (i) zero till rice and zero till wheat (ii) zero till rice and conventional till wheat (iii) conventional till rice and zero till wheat (iv) conventional till rice and conventional till wheat in the main plot and three methods of weed control practices, *viz.* (i) two hand weeding (20 and 40 days after sowing (DAS) for rice and 25 and 50 DAS for wheat) (ii) recommended herbicides butachlor at 1.5 kg/ha pre-emergence followed by 2,4-D at 0.5 kg/ha post-emergence for rice and isoproturon at 0.75 kg/ha + 2,4-D at 0.5 kg/ha post-emergence for wheat (iii) weedy check in sub plot and replicated 4 times. The soil was sandy loam having acidic in reaction (pH 5.43), low in, available nitrogen (242.23 kg/ha), available phosphorus (14.85 kg/ha) potassium (123.0 kg/ha) and medium in organic carbon (0.52%). The direct-seeded rice crop was fertilized with 100 kg N, 40 kg P_2O_5 and 30 kg K_2O/ha and wheat crop was fertilized with the recommended dose of 100 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha. Half dose of N and a full dose of P_2O_5 and K_2O were applied at the time of seeding and remaining nitrogen was applied in two equal splits at maximum tillering and panicle initiation in direct-seeded rice and at crown root initiation and at panicle initiation in wheat. Rice '*Naveen*' and wheat '*K-9107*' was used as test varieties during the study. The total rainfall received during crop season was 1063.7 mm and 1177.0 mm during 2009 and 2010, respectively. Pre-emergence herbicide *i.e.* butachlor was applied just after sowing while post-emergence herbicides *i.e.* isoproturon and 2,4-D were applied at 25 DAS. Observations on weeds were recorded with the help of a quadrate 0.5 × 0.5 m placed randomly at two spots in each plot at 30, 60 and 90 DAS. The data on weeds were subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis. Data on the dry weight of weeds were recorded by cutting weeds at ground level, washed with tap water, sun-dried followed by oven drying at 65°C for 48 hours and then weighed. Weed control efficiency was determined by using standard formula.

RESULTS AND DISCUSSION

Weed compositions

In rice, the experimental field was infested with all the three categories of weed species in weedy check throughout the crop growth in direct-seeded rice during 2009 and 2010. The total number of species was 20, out of which *Echinocloa colona*, *Sorghum halepence* Pers., *Sitaria glauca*, *Digitaria sanguinalis* Scop, *Cynodon dactylon*, *Elusine indica*, *Dactyloctaneum aegiptium*, *Ischaemum rugosum*, among grasses, *Commelina benghalensis*, *Commelina diffusa*, *Ageratum conyzoides*, *Euphorbia hirta*, *Alternanthera sessilis* L, *Ludvigia parviflora*, *Phyllanthus niruri* and *Amaranthus viridis* among broad-leaved weeds and *Cyperus rotundus*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* among sedges were prominent. Among all weed categories grassy, broad-leaved weeds and sedges accounted for 23.1, 59.2 and 17.7%, respectively of total weed density. In wheat during both the years, experimental plot was infested with only two categories *i.e.* broad-leaf weed and grassy weed in weedy check accounting for 94.3 and 5.7% of total weed density. The total number of species was 9, out of which *Coronopus didymus*, *Vicia hirsuta*, *Vicia sativa*, *Anagallis arvensis*, *Medicago denticulata* and *Chenopodium album* in broad-leaved weeds while *Cynodon dectylon*, *Avena fatua and Phalaris minor* in grassy weeds.

Weed density and weed dry matter

Conventional tilled rice after conventional tilled wheat had more number of total weeds (537.6, 321.6 and 199.7 no./m^2 at 30, 60 and 90 days after sowing respectively) and interestingly less total weed dry matter (53.5, 46.7 and 33.3 g m^{-2} at 30, 60 and 90 DAS, respectively) than rice grown after zero tilled wheat. Similarly, conventionally tilled wheat after conventionally tilled rice had more number of total weeds (678.7, 562.4 and 156.1 no./m^2 at 30, 60 and 90 DAS, respectively) and less total weed dry matter (25.8, 15.8 and 13.1 g/m^2 at 30, 60 and 90 DAS, respectively). Conventional tilled plots had more number of weeds competing with crops as compared to zero tilled plots (**Table 1** and **3**). In fact, undisturbed soil conditions induced dormancy in weed seeds present beyond surface layer which causes a decrease in emergence and establishment of weeds in comparison to that of conventional tilled soil (Verma and Srivastava 1989, Gopinath *et al*. 2007). However, under zero tillage condition weeds accumulated more dry matter than those under conventional tillage (**Table 2** and **3**). This might be due to the presence of perennial weeds particularly *Sorghum halepense* in rice and *Cynodon dactylon* in wheat, which grew faster prior to germination of the crop. However, in tilled plots, these weeds were killed at the time of ploughing and so they did not get a chance to grow and compete with rice/wheat.

Among the weed management practices, application of butachlor at 1.5 kg/ha pre-emergence followed by 2,4-D at 0.5 kg/ha post-emergence reduced total weed density (176.4, 118.3 and 66.9 no./m^2 at 30, 60 and 90 DAS, respectively) as well as dry weight (62.0, 29.6 and 23.2 g/m^2 at 30, 60 and 90 DAS, respectively) during both the years compared to two hand weeding at 20 and 40 DAS and weedy check. Similarly isoproturon at 0.75 kg/ha + 2,4-D at 0.5 kg/ha in wheat was found to be the most effective registering significantly lowest number (269.8, 93.9 and 69.5 no./m^2 at 30, 60 and 90 DAS, respectively) as well as dry matter (27.6, 9.8 and 13.7 g/m^2 at 30, 60 and 90 DAS respectively) of total weed at 30, 60 and 90 DAS. The results were in agreement with the findings of Chinnusamy *et al*. (2006) and Singh and Singh (2010).

Yield attributes of rice and wheat/rice equivalent yield

Conventionally tilled rice produced 14.6% higher productive tillers; 3.0% higher panicle length; 9.3% higher filled grain; resulting 25.5% higher grain (3.0 t/ha) and 27.9% higher straw yield (4.2 t/ha) compared to zero tilled rice (2.4 t grain and 3.2 t straw/ha). Similarly, conventionally tilled wheat produced higher productive tillers/m^2, longer spike, grains/spike, and bolder grains; resulting 14.7% higher mean grain (3.5 t/ha) and 17.9% higher mean straw (4.9 t/ha) yield than zero tilled wheat.

Among the weed control method, two hand weeding in rice at 20 and 40 DAS produced 53.3% higher productive tillers, 5.1% higher panicle length, 36.0% higher filled grain/panicle as well as 7.0% higher test weight resulting 105.6% higher grain (3.2 t/ha) and 125.2% higher straw yield (4.7 t/ha) than weedy check and at par with application of butachlor at 1.5 kg/ha pre-emergence followed by 2,4-D at 0.5 kg/ha post-emergence. Similarly, in wheat two hand weeding at 25 and 50 DAS crop recorded higher yield attributing parameters like 31.3% productive tillers/m^2, 5.3% spike length and 8.6% filled grains resulting 36.1% higher grain (3.6 t/ha) and 38.6% higher straw yield (5.1 t/ha) compared to weedy check and at par with application isoproturon at 0.75 kg/ha + 2,4-D at 0.5 kg/ha.The direct seeded rice-wheat sequence with conventional tillage produced higher rice equivalent yield 7.4 t/ha (for 3.1 t/ha rice and 3.6 t/ha wheat).

Table 1. Effect of tillage and weed control on weed density (no./m^2) in direct-seeded rice

Treatment		Weed density											
		Grasses				Sedges				Broad-leaved weeds			
		30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS	
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Tillage													
Rice – Wheat													
ZT - ZT		6.71	6.05	7.90	7.37	5.89	5.81	4.27	3.95	13.11	13.12	7.53	7.15
		(52.7)	(48.1)	(73.5)	(65.5)	(46.6)	(42.4)	(21.8)	(16.8)	(206.9)	(206.3)	(63.3)	(55.9)
ZT – CT		8.07	7.86	7.34	7.00	6.68	6.3	4.53	4.2	13.80	13.55	8.36	7.54
		(70.2)	(74.8)	(62.3)	(56.8)	(52.6)	(47.2)	(24.3)	(19.4)	(222.2)	(217.0)	(85.8)	(63.3)
CT – ZT		10.66	9.95	5.83	5.57	8.81	7.87	5.37	4.89	15.10	14.89	10.38	8.57
		(118.5)	(105.3)	(37.7)	(34.2)	(90.5)	(70.5)	(30.6)	(25.8)	(255.3)	(256.0)	(119.2)	(79.9)
ZT – ZT		11.67	10.8	5.11	4.97	10.19	9.23	5.48	5.33	16.05	15.53	10.48	9.27
		(155.5)	(126.9)	(30.6)	(27.6)	(123.5)	(104.1)	(33.8)	(30.9)	(285.9)	(279.3)	(124.5)	(93.3)
LSD (p=0.05)		2.11	1.20	1.56	1.44	1.72	1.50	0.76	0.65	1.10	1.04	1.97	0.95
Weed management													
Rice	Wheat												
Weedy check	Weedy check	11.96	11.79	17.06	15.98	12.14	11.3	7.08	6.36	22.02	22.51	13.34	11.24
		(158.3)	(147.6)	(295.6)	(264.4)	(161.5)	(136.8)	(50.6)	(41.9)	(486.2)	(508.8)	(184.1)	(130.4)
Butachlor 2,4-D	Isoproturon +2,4-D	7.54	6.60	7.96	7.73	4.68	4.39	3.42	3.44	9.8	9.23	6.59	6.05
		(62.2)	(56.1)	(65.9)	(62.0)	(24.1)	(21.1)	(12.9)	(11.9)	(102.3)	(87.0)	(46.2)	(37.6)
Hand weeding	Hand weeding	8.33	7.60	8.97	8.65	6.86	6.23	4.24	3.98	11.72	11.08	7.64	7.11
		(77.3)	(62.7)	(84.9)	(77.6)	(49.3)	(40.2)	(19.3)	(15.9)	(139.3)	(123.3)	(63.5)	(51.3)
LSD (p=0.05)		2.05	1.98	1.38	1.4	1.53	1.47	0.97	0.74	1.27	0.85	1.44	1.20

DAS, Days after sowing; Data were subjected to a square root transformation. Data are given in parenthesis are original values; ZT – Zero tillage, CT – Conventional tillage

Table 2. Effect of tillage and weed control on weed dry matter production (g/m^2) in direct-seeded rice

Treatment		Weed dry matter production											
		Grasses				Sedges				Broad-leaved weeds			
		30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS	
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Tillage													
Rice – Wheat													
ZT - ZT		6.55	5.87	7.90	7.37	3.92	3.52	3.53	3.28	10.50	9.50	4.86	4.45
		(47.9)	(39.2)	(73.5)	(65.5)	(16.2)	(12.8)	(12.7)	(10.9)	(113.7)	(95.3)	(25.8)	(22.3)
ZT – CT		5.59	5.42	7.34	7.00	3.43	3.25	3.33	3.07	10.03	9.17	4.41	3.99
		(33.1)	(30.5)	(62.3)	(56.8)	(12.6)	(11.2)	(11.3)	(9.7)	(105.1)	(88.6)	(23.6)	(18.7)
CT – ZT		4.27	3.97	5.83	5.57	2.50	2.43	2.59	2.27	6.95	5.48	3.68	3.31
		(20.0)	(16.6)	(37.7)	(34.2)	(7.1)	(6.4)	(6.9)	(5.4)	(49.8)	(32.8)	(14.7)	(12.5)
ZT – ZT		3.85	3.31	5.11	4.97	2.40	2.36	2.46	2.20	5.80	5.07	3.47	2.98
		(16.7)	(11.6)	(30.6)	(27.6)	(6.6)	(5.9)	(6.4)	(4.9)	(36.0)	(30.2)	(13.2)	(10.6)
LSD (p=0.05)		1.15	0.89	1.23	0.71	0.81	0.31	0.55	0.38	1.26	0.64	0.47	0.60
Weed management													
Rice	Wheat												
Weedy check	Weedy check	6.86	6.27	9.83	9.59	4.27	4.01	3.72	3.51	10.33	9.91	6.08	5.74
		(49.2)	(42.0)	(102.9)	(95.8)	(18.7)	(16.1)	(14.1)	(12.3)	(112.3)	(102.9)	(37.8)	(33.6)
Butachlor 2,4-D	Isoproturon + 2,4-D	3.40	3.28	4.5	4.2	1.92	1.89	2.22	2.06	7.10	5.67	2.61	2.07
		(13.1)	(11.3)	(21.2)	(17.8)	(4.1)	(3.6)	(4.9)	(4.1)	(55.1)	(36.7)	(7.1)	(4.2)
Hand weeding	Hand weeding	4.93	4.38	5.3	4.89	3.00	2.76	3.00	2.56	7.53	6.34	3.63	3.24
		(26.1)	(20.0)	(28.9)	(24.6)	(9.0)	(7.5)	(8.9)	(6.7)	(61.0)	(45.7)	(13.2)	(10.4)
LSD (p=0.05)		0.78	0.55	1.07	0.71	0.51	0.38	0.52	0.43	0.99	1.08	0.62	0.30

DAS, Days after sowing; Data were subjected to a square root transformation. Data are given in parenthesis are original values; ZT – Zero tillage, CT – Conventional tillage

Table 3. Effect of tillage and weed control on weed density (no./m^2) and weed dry matter production (g/m^2) in wheat

Treatment	Weed density								Weed dry matter production							
	Grasses				Broad-leaved weeds				Grasses				Broad-leaved weeds			
	30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS		30 DAS		60 DAS	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
Tillage																
Rice – Wheat																
ZT - ZT	4.11	3.90	3.62	2.39	19.58	16.79	14.9	13.49	2.71	2.54	2.14	1.96	7.92	7.45	6.97	4.92
	(17.8)	(18.8)	(17.0)	(7.2)	(430.0)	(301.7)	(274.0)	(261.3)	(7.4)	(6.9)	(4.8)	(3.9)	(65.2)	(58.5)	(64.7)	(29.4)
ZT – CT	5.78	5.37	6.6	4.94	23.28	21.02	19.94	17.1	1.63	1.14	1.44	1.29	5.67	4.76	4.17	3.27
	(34.6)	(33.0)	(51.5)	(27.8)	(588.7)	(460.7)	(502.0)	(354.0)	(2.6)	(0.9)	(1.7)	(1.3)	(34.0)	(26.3)	(26.7)	(12.7)
CT – ZT	4.63	4.04	3.97	3.28	20.24	17.79	16.14	14.21	2.30	2.10	1.98	1.85	7.41	6.97	6.11	4.85
	(22.5)	(20.1)	(21.3)	(11.3)	(449.7)	(344.3)	(319.7)	(279.2)	(5.4)	(4.5)	(3.9)	(3.3)	(59.3)	(51.1)	(51.1)	(27.0)
ZT – ZT	6.74	6.32	7.88	5.26	25.02	23.84	22.08	18.56	1.45	1.07	1.27	1.18	4.92	4.62	3.62	2.64
	(48.7)	(44.7)	(83.7)	(34.1)	(669.7)	(594.3)	(605.7)	(401.3)	(1.8)	(0.7)	(1.3)	(1.0)	(26.3)	(22.7)	(20.0)	(9.4)
LSD (p=0.05)	1.02	0.96	1.77	1.55	2.63	3.07	2.93	1.82	0.64	0.85	0.32	0.28	0.92	0.96	1.34	1.01
Weed management																
Rice – Wheat																
Weedy check – Weedy check	6.82	7.63	8.14	5.84	30.82	26.4	29.96	26.73	2.91	2.03	2.33	2.15	8.39	7.82	9.30	6.24
	(49.1)	(60.0)	(83.8)	(39.1)	(912.9)	(655.5)	(935.3)	(719.5)	(7.2)	(4.6)	(5.3)	(4.5)	(74.0)	(63.9)	(97.4)	(40.5)
Butachlor 2,4-D – Isoproturon +2,4-D	4.02	3.08	3.25	2.64	16.50	15.71	9.66	7.48	1.54	1.39	1.32	1.14	5.08	4.61	3.02	2.39
	(17.0)	(10.1)	(13.0)	(8.6)	(264.5)	(248.0)	(98.5)	(67.6)	(2.4)	(1.9)	(1.4)	(1.0)	(27.1)	(23.6)	(10.0)	(7.1)
Hand weeding – Hand weeding	5.11	4.03	5.15	3.42	20.73	19.36	15.18	13.31	1.76	1.71	1.48	1.42	5.98	5.43	3.34	3.13
	(26.6)	(17.3)	(33.4)	(12.6)	(426.3)	(372.3)	(242.3)	(184.8)	(3.3)	(3.3)	(2.0)	(1.7)	(37.4)	(31.4)	(14.4)	(11.2)
LSD (p=0.05)	0.68	0.64	1.74	0.67	2.80	2.15	2.39	1.56	0.32	0.38	0.29	0.29	0.98	1.03	1.51	0.77

DAS, Days after sowing; Data were subjected to a square root transformation. Data are given in parenthesis are original values; ZT – Zero tillage, CT – Conventional tillage

Table 4. Effect of tillage and weed control on yield attributes of rice and wheat and rice equivalent yield (pooled data)

Treatment	Rice							Wheat							Rice equivalent yield (t/ha)
	Productive tillers (no./m^2)	Panicle length (cm)	Filled grains/ panicle	Unfilled grains/ panicle	1000 grains weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Productive tillers (no./m^2)	Spike length (cm)	Filled grains/ panicle	Unfilled grains/ panicle	1000 grains weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	
Tillage															
Rice – Wheat															
ZT - ZT	249	17.9	58	14.5	20.0	2.3	3.1	217	10.4	44	10	42.2	3,0	4.1	5.9
ZT – CT	277	18.2	60	14.9	20.4	2.5	3.4	233	10.8	46	10	42.4	3.4	4.8	6.8
CT – ZT	297	18.5	64	15.9	20.9	2.9	4.0	221	10.5	45	10	42.3	3.1	4.3	6.7
ZT – ZT	305	18.7	65	16.2	21.4	3.1	4.3	240	10.8	47	10	42.1	3.6	5.1	7.3
LSD (p=0.05)	28.0	NS	4.1	0.7	NS	2.9	3.5	NS	NS	NS	NS	NS	2	3	4.5
Weed management															
Rice – Wheat															
Weedy check – Weedy check	210	17.8	50	12	20.0	1.6	2.2	192	10.3	43.2	9.8	42.2	2.7	3.7	4.8
Butachlor + 2,4-D – Isoproturon + 2,4-D	314	18.4	67	17	20.8	3.3	4.4	239	10.7	46.3	10.2	42.1	3.5	4.9	7.4
Hand weeding – Hand weeding	323	18.7	68	17	21.4	3.3	4.7	252	10.9	46.9	10.3	42.4	3.7	5.1	7.8
LSD (p=0.05)	26.1	0.9	4.6	1.0	1.7	2.8	2.1	16	0.5	2.6	0.6	2	2	3	4.4

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Control of broad-leaved weeds in wheat under eastern sub-Himalayan plains

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ABSTRACT

A study was undertaken during winter seasons of 2016-17 and 2017-18 at Uttar Banga Krishi Viswavidyalaya, Coochbehar, West Bengal to assess the comparative efficacy of various herbicides and to identify the effective herbicides for controlling broad-leaved weed flora in wheat. The experiment was laid out in a Randomized Block Design (RBD) with eleven herbicides combination *viz*. halauxifen-methyl ester+ florasulam 40.85% WG + polyglycol; metsulfuron methyl 20 WG + surfactant; carfentrazone 40 DF; 2,4-D Na 80 WP; 2,4-D E 38 EC; metsulfuron + carfentrazone +surfactant; 2,4-D-Na + carfentrazone; 2,4-D E + carfentrazone , halauxifen-methyl + florasulam+ carfentrazone + surfactant including a weedy check and weed free treatment. It was revealed that *Polygonum* alone constituted almost 72% of the total broad leaved weed population in both the years. Among the herbicidal treatments, metsulfuron + carfentrazone + surfactant recorded significantly lesser weed population (10.0 and 2.3/m^2 during 30 and 60 days after spraying of post-emergence herbicides, respectively) *vis-à-vis* weed dry weight (11.2 and 4.5 g/m^2 during 30 and 60 days after spraying of post-emergence herbicides, respectively) . This combination also recorded the highest broad leaf weed control efficiency (90.1 and 99.0% at 30 and 60 days after spraying, respectively) with the lowest weed index 6.0.The new molecule halauxifen-methyl ester + florasulam in combination with carfentrazone recorded 88.1 and 94.0% weed control efficiency. It was noted that *Polygonum* was killed by halauxifen-methyl ester + florasulam 40.85% WG + polyglycol, but it could not control *Physalis minima*, the second most important weed after *Polygonum*. Weed free treatment recorded significantly higher grain yield (5.39 t/ha) followed by metsulfuron + carfentrazone + surfactant treated plots (5.04 t/ha), the best performed treatments among various post-emergence herbicides combination used in the experiment. According to the linear regression, wheat crop was likely to produce very poor grain yield (less than 1.50 t/ha) when weed biomass exceeds 400 g/m^2.

INTRODUCTION

Weed infestation is one of the major biotic factors limiting wheat production and productivity. The losses caused by weeds depend on their types, abundance and environmental factor (Chhokar *et al*. 2012), and weeds account for 0-80% yield reduction depending upon the weed species and infestation and caused depletion of soil water up to 6.5 cm (Mehra and Gill 1988, Khera *et al*. 1995). Again, weeds tend to shift with the change in tillage, agronomic management, and cropping system although there are other factors that govern the changes in the weed flora. Despite being a serious problem in crop field, this problem always remains under-estimated although they cause higher reduction in economic yield of crops than other pests and diseases. Chemical herbicides are most important tools in weed management to maintain yield and quality of crop. Various researchers have investigated the efficacy of different herbicides for control of weeds in wheat crop mostly targeting towards *Phalaris minor*. But in those areas where *Phalaris* is not a big problem, alternate herbicides have to be tested. In this part of eastern sub-Himalayan plains, it has been reported that various species of *Polygonum, viz. Polygonum persicaria, Polygonum pensylvanicum, Polygonum hydropiper* and *Polygonum orientale* are notorious weeds in wheat, which accounts for a major share of total weed flora.

Severe problem of *Solanum nigrum* and *Physalis minima* were also reported from various parts of Eastern India (Chhokar *et al.* 2012). Broad leaved weeds posed a severe problem in these areas instead of grasses. Under this situation, farmers mostly depend on 2,4-D, which is not always very effective against these weeds. For control of broad-leaf weeds in wheat, three major herbicides used in India are metsulfuron, 2,4-D and carfentrazone (Chhokar *et al.* 2007b). Some of the post-emergence contact herbicides like carfentrazone-ethyl are less effective on weeds having advanced stage, as well as, unable to control the subsequent weeds emerging after application due to its lack of residual activity (half-life of carfentrazone is 2-5 days) in soil (Lyon *et al.* 2007, Willis *et al.* 2007). To broaden the spectrum of weed kill and to provide the long term residual weed control, the use of herbicide mixture/ combinations are advocated. Herbicide mixture besides providing control of complex weed flora will also help in managing and delaying the herbicide resistance problem. Keeping these aspects in background, the study was undertaken with the objectives to study the broad-leaved weed flora in wheat and to study the comparative efficacy of various herbicides for controlling broad-leaved weed flora in wheat.

MATERIALS AND METHODS

The experiment was carried out in the Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal located at 26°24'02.2"N latitude, 89°23'21.7"E longitude and at an elevation of 43 meters above mean sea level. It was carried out for two consecutive years, *i.e.*, *Rabi* seasons of 2016-17 and 2017-18. The soil, on which the experiment was carried out, was sandy loam in texture having good drainage facility with 0.89% organic C, 153 kg/ha of mineralizable N, 19.2 kg/ha of available phosphorus, 141 kg/ha of available potassium and a pH of 5.54.

The experiment was laid out in a randomized block design (RBD) with 3 replicates. Eleven various herbicides combination including a weedy check and weed free treatment were randomly allotted to various plots under each replication. The sizes of each experimental plot was 5 x 3 m. The treatments comprised of the following : halauxifen-methyl ester + florasulam 40.85% WG at 12.76 g/ha + polyglycol (surfactant) at 750 ml/ha; metsulfuron-methyl 20 WG at 4 g/ha + surfactant; carfentrazone 40DF at 20 g/ha; 2,4-D Na 80 WP at 500 g/ha; 2,4-D E 38 EC at 500 ml/ha; metsulfuron (4 g/ha) + carfentrazone (20 g/ha) + surfactant; 2,4-D Na (500 g/ha) + carfentrazone (20 g/ha); 2,4-D E (500 ml/ha) + carfentrazone (20 g/ha); halauxifen-methyl + florasulam (12.76 g/ha) + carfentrazone (20 g/ha) + surfactant; weedy check and weed free.

The variety used in the experiment was '*K 0307*', an irrigated timely sown variety for '*NEPZ*'. Seeds were sown in lines 22.5 cm apart with a seed rate of 100 kg/ha. The fertilizer dose was kept at 150 kg nitrogen, 60 kg phosphorus and 40 kg potassium/ha. Nitrogen fertilizers were applied in three splits (75 kg/ha as basal, 37.5 kg/ha each at 3 weeks and 6 weeks after sowing). A blanket dose of clodinafop 60 g/ha was applied 5 days before the broad-leaf herbicide application to control grassy weeds and all the post-emergence herbicides were applied at 30-32 days after sowing. Herbicides were applied with the use of a knapsack sprayer fitted with a flat-fan nozzle and water as a carrier at 375 litre/ha for post-emergence spray. A three nozzles boom with flat fan nozzle tip was used for spraying. For tank mix herbicides, herbicides were properly mixed in stock solution prior to adding in spray tank avoiding mixing the herbicides directly in spray tank. Quadrates (50 x 50 cm) were established in each plot after pre-emergence applications, 1-2 days after seeding. Initial broad-leaf weed count was taken from four permanent quadrates before application of post-emergence herbicides. For broad-leaf count and weed biomass at 30 days after post-emergence herbicide application, count was taken from all four permanent quadrates and weed biomass from only two random quadrates. The broad leaf count and biomass 60 days after post-emergence herbicide application were taken from the two remaining permanent quadrates. Weeds were cut at ground level, washed with tap water, sun-dried, oven-dried at 70 degree centigrade for 48 hours, and then weighed. Yield attributes were taken accordingly at harvest, while the grain yield was measured from the entire plot area of 15 m^2 and expressed in kg/ha at 14% moisture.

Weed control efficiency (WCE) and weed index (WI) was also calculated on the basis of weed biomass and grain yield, respectively. Herbicides Efficiency Index (HEI), indicating the weed killing potential of different herbicide treatments and their phyto-toxicity related to the crop,was calculated by the following formula as given by Krishnamurthy *et al.* (1995): HEI= [(Yield in treated plot – Yield in control plot)/ Yield in control plot]x 100. Data on weed density and dry weight were subjected to $(\sqrt{x+1})$ square root transformation to normalize the distribution. Mean separations for different treatments under different parameters were performed using Least Significance Difference

(LSD) test $\sqrt{x+0.5}$. Entire statistical analysis was carried out using statistical analysis system (SAS) software (version 9.2).

RESULTS AND DISCUSSION

Weed flora

The broad-leaf weed flora in wheat as emerged in the experiment was identified and their sequence of emergence with special characteristics was noted by regular survey on weeds throughout the growing period. At 60 days after sowing, the major broad-leaved weeds found in the field were *Polygonum persicaria*, *Polygonum pensylvanicum, Polygonum hydropiper, Polygonum orientale, Chenopodium album, Physalis minima, Oxalis corniculata, Portulaca oleracea* , *Gnaphalium luteo-album, Centella asiatica* and *Cronopus didymus* . Various species of *Polygonum* was dominant in all the stages of crop growth. During 60 days, *Polygonum* alone constituted almost 72% of the total broad-leaved weed population in both the years (**Table 1**). It was further noted that *Polygonum hydropiper* was dominant up to the tillering stages of the crop; later on *Polygonum orientale* emerged and become dominant at later stages. Rahaman and Mukherjee (2008) also reported that the major weed flora observed in *terai* region of West Bengal were various species of *Polygonum.* Among the weed species other than the *Polygonum*, *Physalis minima* shared 7.27 and 8% of the total broad leaved weeds in 2016-17 and 2017-18, respectively.

Weed density and dry weight

Weed density at various stages of growth varied significantly under various herbicides application **Table 2**. Except weedy check, all the herbicides combination used in the experiment reduced the broad-leaved weed population significantly after 30 and 60 days of spraying post-emergence herbicides, but the degree of reduction is different in different combination of herbicides. Among the herbicidal treatments, metsulfuron + carfentrazone + surfactant recorded significantly lesser weed population (10.0 and 2.3/m^2 during 30 and 60 days after spraying of post-emergence herbicides, respectively); however, when these two herbicides were applied separately the degree of reduction in broad-leaved weeds was much lesser than their combination reflecting the superiority of this combination in suppressing the broad-leaved weed flora in wheat. The weedy check treatments recorded as high as 124.7 and 178.7/m^2 of broad-leaved weeds during 30 and 60 days after spraying of post-emergence herbicides, respectively. Singh *et al.* (2011) observed that pre-mix carfentrazone + metsulfuron 25 g/ha with 0.2% NIS reduced the population of weeds in wheat by 97 and 99% during 2009-10 and 2010-11, respectively. On an average, it provided 95% control of infested weeds. There was significant variation in dry weight of the weeds obtained under various herbicides treatment during both the years of experimentation. The lowest weed dry weight (11.2 and 4.5 g/m^2 during 30 and 60 days after spraying of post-emergence herbicides, respectively) was also achieved with metsulfuron + carfentrazone + surfactant treatment.

Table 1. Distribution of various broad-leaved weed species in weedy check plot in wheat

Weed species	2016-17		2017-18	
	Total no./m^2	Total weeds (%)	Total no./m^2	Total weeds (%)
Polygonum persicaria	13	7.9	21	16.8
Polygonum pensylvanicum	30	18.2	18	14.4
Polygonum hydropiper	64	38.8	45	36.0
Polygonum orientale	12	7.3	7	5.6
Chenopodium album	8	4.8	4	3.2
Physalis minima	12	7.3	10	8.0
Oxalis corniculata	0	0	7	5.6
Portulaca oleracea	7	4.2	0	0.0
Gnaphalium luteo-album	11	6.7	8	6.4
Centella asiatica	3	1.8	5	4.0
Cronopus didymus	5	3.0	0	0
Total	165		125	

WCE, WI and HEI

Among the herbicidal treatments, the highest broad-leaf weed control efficiency (90.1 and 99.0% at 30 and 60 days after spraying, respectively) was achieved with metsulfuron + carfentrazone + surfactant treatment (**Table 3**) though the weed free plot recorded 100% weed control efficiency. It was followed by halauxifen-methyl + florasulam + carfentrazone + surfactant (88.8 and 94.4% at 30 and 60 days after spraying, respectively). It was noted that when these herbicides were sprayed alone, the weed control ability was much lesser than their combination with carfentrazone. At 60 days after spraying, the combination metsulfuron + carfentrazone + surfactant was as good as weed free treatment. It was evident that post-emergence herbicides, *viz.* halauxifen-methyl ester + florasulam 40.85% WG + polyglycol, metsulfuron-methyl and carfentrazone had a better broad-leaf killing ability as reflected from the WCE value over 2,4-D Na and 2,4-D E, the traditional chemical broad-leaf killer. When these herbicides were combined with carfentrazone, the WCE was much higher than their respective sole

Table 2. Broad-leaf weed density and dry weight as influenced by various post-emergence herbicides in different stages (pooled over 2 years)

Treatment	Weed density (no./m^2)			Weed dry weight (g/m^2)	
	Before spraying	30 DAS	60 DAS	30 DAS	60 DAS
Halauxifen-methyl ester + florasulam 40.85% WG + polyglycol	9.0 (80.7)	5.9 (34.3)	4.6 (20.7)	4.5 (19.1)	7.5 (55.3)
Metsulfuron-methyl 20 WG + surfactant	8.5 (70.7)	6.5 (42.0)	3.9 (14.3)	5.0 (23.9)	7.1 (50.1)
Carfentrazone 40DF	8.7 (74.0)	6.2 (38.0)	3.9 (14.4)	4.2 (16.9)	7.1 (45.2)
2,4-D Na 80 WP	11.6 (135.0)	6.7 (43.7)	8.6 (72.3)	6.2 (37.4)	13.7 (186.9)
2,4-D E 38 EC	9.4 (87.7)	5.7 (32.0)	6.1 (36.3)	5.6 (30.9)	10.7 (112.9)
Metsulfuron + carfentrazone + surfactant	7.3 (52.0)	3.3 (10.0)	1.8 (2.3)	3.5 (11.2)	2.3 (4.5)
2,4-D Na + carfentrazone	6.3 (39.3)	4.3 (17.3)	4.9 (22.7)	4.2 (16.3)	9.3 (85.3)
2,4-D E + carfentrazone	6.9 (46.3)	4.3 (18.0)	4.2 (16.7)	3.8 (13.3)	8.7 (75.4)
Halauxifen-methyl + florasulam + carfentrazone + surfactant	7.8 (59.7)	5.0 (24.0)	3.6 (12.3)	3.7 (12.5)	5.3 (27.4)
Weedy check	9.9 (96.7)	11.2 (124.7)	13.4 (178.7)	10.6 (111.8)	21.3 (451.5)
Weed free	1.0 (0)	1.0 (0.0)	1.0 (0)	1.0 (0)	1.0 (0)
LSD (p=0.05)	0.60	0.54	0.48	0.48	0.76

Figures in the parentheses are original values. Data subjected to ($\sqrt{x+1}$) square root transformation; DAS - Days after spraying

Table 3. Weed control efficiencies and weed index of various herbicidal treatments (pooled over 2 years)

Treatment	Weed control efficiency (%)		Weed index (%)	Herbicides efficiency index (%)
	30 DAS	60 DAS		
Halauxifen-methyl ester + florasulam 40.85% WG + polyglycol 26-2 N	82.9	87.7	17.5	248.40
Metsulfuron-methyl 20 WG + surfactant	78.6	88.9	13.1	260.50
Carfentrazone 40DF	84.9	88.9	26.9	211.20
2,4-D Na 80 WP	66.6	58.6	30.7	162.40
2,4-D E 38 EC	72.4	75.0	24.2	192.15
Metsulfuron + carfentrazone + surfactant	90.1	99.0	6.0	291.45
2,4-D Na + carfentrazone	85.4	81.1	12.8	254.25
2,4-D E + carfentrazone	88.1	83.3	10.3	258.40
Halauxifen-methyl + florasulam+ carfentrazone + surfactant	88.8	94.0	9.3	284.30
Weedy check	0.0	0.0	76.5	0.00
Weed free	100.0	100.0	0.0	318.60

application. It was reflected from the study that combination of herbicides in the form of tank mix formulation had a greater broad leaf controlling ability than sole application of the individual herbicides.

Among various weed control treatments, the lowest weed index was recorded in metsulfuron + carfentrazone + surfactant treatment (6%) closely followed by halauxifen-methyl + florasulam+ carfentrazone + surfactant treatment (9.3%). Lower values directly reflected the superiority of this combination in suppressing the weed flora with increased yield performances and selectivity. As far as the herbicides efficiency index was concerned, higher values were reflected with tank mixture of various post-emergence herbicides compared to their sole application. Metsulfuron + carfentrazone + surfactant recorded the maximum herbicides efficiency index (291.45%) closely followed by halauxifen-methyl + florasulam + carfentrazone + surfactant (284.30%).

Yield components and grain yield

Data in **Table 4** indicated the superiority of weed free treatments in terms of grain yield. Weed free treatment recorded significantly higher grain yield (5.39 t/ha), which was followed by metsulfuron + carfentrazone +surfactant treated plots (5.04 t/ha), the best performed treatments among various post-emergence herbicides combination used in the experiment. There was no significant difference in yield achieved with weed free treatments and treatments comprising of metsulfuron + carfentrazone + surfactant. Halauxifen-methyl + florasulam + carfentrazone + surfactant treatment also recorded a better yield performance (4.91 t/ha), being at par with metsulfuron + carfentrazone + surfactant. In weedy check the grain yield was very poor (1.29 t/ha) signifying the huge weed pressure on the crop. The yield and yield components, *viz.* spike no./m^2, no. of grains/spike and 1000-grain weight were significantly increased with different herbicide treatments compared with weedy check. Among the herbicidal treatments, metsulfuron + carfentrazone + surfactant recorded significantly lesser weed population *vis-a-vis* lesser weed biomass reflecting the superiority of this combination in suppressing the broad-leaved weed flora in wheat. All sorts of broad leaved weeds were controlled through this

Table 4. Yield components and yields of wheat under various herbicides combination (pooled over 2 years)

Treatment	No. of spike/ m^2	No. of grains/ spike	Test weight (g)	Grain yield (t/ha)
Halauxifen-methyl ester + florasulam 40.85% WG + polyglycol 26-2 N	295	41.50	38.85	4.48
Metsulfuron-methyl 20 WG + surfactant	304	41.10	40.10	4.64
Carfentrazone 40DF	262	41.60	39.45	4.01
2,4-D Na 80 WP	254	38.50	38.45	3.37
2,4-D E 38 EC	272	41.95	38.05	3.75
Metsulfuron + carfentrazone + surfactant	336	44.55	42.45	5.04
2,4-D Na + carfentrazone	299	39.70	38.25	4.55
2,4-D E + carfentrazone	303	41.20	42.50	4.60
Halauxifen-methyl + florasulam + carfentrazone + surfactant	321	38.10	42.20	4.91
Weedy check	88	32.55	34.85	1.29
Weed free	351	46.15	43.00	5.39
LSD (p=0.05)	38.1	3.9	3.4	0.4

combination and it was almost weed free after 30-35 days of spraying. Though *Polygonum* was killed by halauxifen-methyl ester + florasulam 40.85% WG + polyglycol, it could not control *Physalis minima*. Even *Physalis minima* was not controlled by application of 2,4-D or carfentrazone when sprayed alone which ultimately reflected the trends of overall yield performances. Complete control of *Physalis* was achieved through metsulfuron + carfentrazone mixture only. Carfentrazone was able to kill all sorts of broad leaved weeds very fast, but could not control the second flushes of weeds.

The responses of wheat yield to weed biomass at 60 days after spraying of post-emergence herbicides were represented separately in a linear diagram (**Figure 1**). The functional relation between the weed biomass and grain yield was expressed in the equation $y = m.x + c$. The value of coefficient of regression (R^2) was 0.95 which implied that 95 % of the yield was contributed by the single factor, weed management. This strong correlation was suggestive of the influence of weed control on the ultimate output, *i.e*., the grain yield of the crop. The results clearly highlighted the poor competitive ability of wheat with weeds and the need to control them effectively during the whole growing season. According to the linear regression, wheat crop was likely to produce very poor grain yield (less than 1.5 t/ha) when weed biomass exceeds 400 g/m^2. On the basis of this field study, it can be concluded that

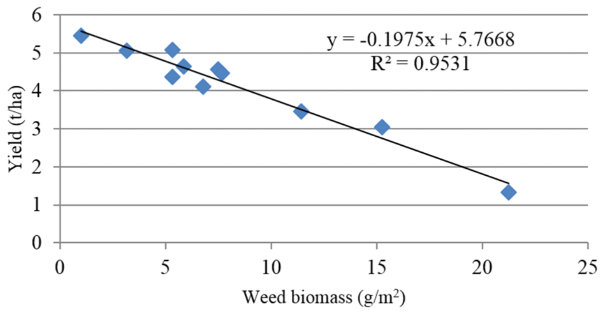

Figure 1. Relationship between weed biomass and grain yield

metsulfuron + carfentrazone + surfactant as post-emergence would be the most effective herbicides combination for controlling the broad-leaf weed flora in wheat under eastern sub-Himalayan plains.

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Comparative study on weed control efficacy of different pre-and post-emergence herbicides in *Kharif* maize

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ABSTRACT

A field experiment was conducted at Research Farm of Punjab Agricultural University, Ludhiana during *Kharif* 2016 and 2017 to find out the best chemical weed management practices in maize. Ten treatments were evaluated in a randomized block design with three replications. Treatments consisted of pre-emergence (PE) and post-emergence (PoE) herbicide applications along with weed-free check and weedy check. Experimental results indicated that pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS as PoE recorded lowest weed index (4.9 and 3.9% respectively, during *Kharif* 2016 and 2017) followed by treatment atrazine 1.5 kg/ha as pre-emergence *fb* tembotrione 120 g/ha as PoE at 25 DAS (5.6 and 4.4%, respectively). Grain yield was significantly higher (6.71 and 6.67 t/ha, respectively) with treatment weed-free than all other treatments however, it was statistically at par with treatment pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS as PoE (6.38 and 6.41 t/ha, respectively during *Kharif* 2016 and 2017) followed by atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha as PoE at 25 DAS (6.34 and 6.37 t/ha, respectively).

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereals of the world and has attained a commercial crop status and also has scope to increase the present yield. Maize, which is mostly grown during *Kharif* rainy season, faces a formidable weed problem competing severely for growth resources resulted in yield losses from 33 to 50% Sharma *et al.* (2000). Maximum yield loss due to weed competition occurs during the first 3-6 weeks, *i.e.*, before the canopy has developed thick enough to smother the weeds (Shad *et al.* 1993). Wider row spacing and initial slow crop growth (Nagalakshmi *et al.* 2006) makes maize highly sensitive to weed competition up to 6 weeks growth period. Thus, to realize optimum yield, thorough weed management is considered critical during the initial 6 weeks of crop growth to minimize crop-weed competition.

Management of weeds is considered to be an important factor for achieving higher productivity. Due to increased cost and non availability of manual labour in required number for timely hand weeding, the role of herbicide is a significant preposition. Herbicides not only control the weeds timely and effectively, but also offer great scope for minimizing the cost of weed control irrespective of the situation. Use of pre- and post-emergence application of herbicides would make herbicidal weed control more acceptable to farmers. Usage of PE herbicides assumes greater importance in the view of their effectiveness from initial stages. Pre-emergent application of herbicides will control the weeds up to 25 days and after that PoE application is given so that further growth of weeds can also be controlled. Pre-and post-emergence herbicides will be an ideal means for controlling the weeds in view of economics and effectiveness in maize. Keeping above in view, an study was carried out to study the sequential application of pre-emergence and post-emergence herbicides in maize during *Kharif* 2016 and 2017.

MATERIALS AND METHODS

A field experiment was conducted at the Research Farm of Punjab Agricultural University, Ludhiana during *Kharif* 2016 and 2017. The soil of the experimental field was loamy sand in texture, low in available nitrogen (132.5kg/ha), medium in available phosphorus (20.4 kg/ha) and potash (183.5 kg/ha). The experiment was laid out in a randomized block design (RBD) with the following treatments *viz.* control (weedy check), weed-free, atrazine 1.5 kg/ha as pre-emergence (PE), atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha as PE, atrazine 1.5 kg/ha + 2,4-D amine 0.4 kg/ha at 25 days after sowing (DAS) as post-emergence (PoE), halosulfuron 90 g/ha at 25 DAS, atrazine 1.5 kg/ha as PE followed by (*fb*) halosulfuron 90 g/ha at 25 DAS, tembotrione 120 g/ha as PoE at 25 DAS, pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS as PoE and atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha as PoE at 25 DAS and replicated thrice. Maize hybrid '*PMH-1*' was sown on 08.07.2016 and 14.07.2017, during 2016 and 2017, respectively at 60 x 20 cm spacing. Before sowing, the field was thoroughly ploughed and leveled. The crop was fertilized evenly irrespective of treatments with $N:P_2O_5:K_2O$ (125:60:30 kg/ha), where N was applied in three equal splits at the time of sowing, at knee high and tasseling stage.

Pre-emergence herbicides were applied within two days after sowing. Post-emergence herbicides were applied at 25 DAS. All the herbicides were sprayed as per the treatments. Weed density was recorded at 50 DAS using a quadrate of 100 x 100 cm (1 m^2) size from the center of the plot. The entire weeds inside the quadrate were uprooted and cut close to the transition of root and shoot in each plot and collected for dry matter accumulation (biomass). The samples were first dried in sun and then kept in an oven at 70 ± 2°C. The dried samples were weighed and expressed as biomass (g/m^2). Square root transformation was done for weed density and weed biomass by using the formula x + 0.5. Weed control efficiency (WCE) and weed index (WI) were calculated using formulae as given by Gill and Kumar (1969), Mani *et al.* (1973).

RESULTS AND DISCUSSION

Effect of herbicides on weed density and dry weight

Weed density and weed dry weight at 50 DAS was significantly influenced by weed management practices in maize (**Table 1**). Application of atrazine 1.5 kg/ha as PE followed by halosulfuron 90 g/ha at 25 DAS recorded significantly lesser grassy weed count (2.8 and 3.5 number/m^2) and weed dry weight (1.5 and 2.1 g/m^2) on 50 DAS and it was statistically at par with the application of halosulfuron 90 g/ha at 25 DAS, pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS and atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha at 25 DAS during the years 2016 and 2017, respectively.

The broad-leaved weeds (BLW) counts during 2016 and 2017 showed that the application of atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha as PoE recorded excellent control on BLW (2.4 and 2.5 number/m^2, respectively) and weed dry weight (2.1 g/m^2 each) on 50 DAS and it was significantly superior to the application of atrazine 1.5 kg/ha as PE (4.1 no./m^2 each) and (3.6 and 3.5 g/m^2, respectively), atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha as PE (3.5 no./m^2 each) and weed dry weight (3.4 and 3.3 g/m^2, respectively) and atrazine 1.5 kg/ha + 2,4-D amine 0.4 kg/ha as PoE (3.4 no./m^2 each) and weed dry weight (3.2 and 2.9 g/m^2, respectively). These results are in accordance with the findings of Swetha *et al.* (2015) and Sivamurugan *et al.* (2017).

Table 1. Effect of different pre and post-emergence herbicides on weed density and weed dry weight of *kharif* maize

Treatment	Weed density (no./m^2) at 50 DAS						Weed dry weight biomass (g/m^2) at 50 DAS					
	2016			2017			2016			2017		
	Grasses	Broad leaf	Sedges	Grasses	Broad leaf	Sedges	Grasses	Broad leaf	Sedges	Grasses	Broad leaf	Sedges
Atrazine 1.5 kg/ha as pre-emergence (PE)	18.7 (4.4)	16.0 (4.1)	24.7 (5.1)	23.0 (4.9)	16.0 (4.1)	30.0 (5.6)	6.0 (2.6)	12.3 (3.6)	10.1 (3.3)	8.3 (3.0)	11.6 (3.5)	10.4 (3.4)
Atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha as PE	16.0 (4.1)	11.7 (3.5)	20.7 (4.7)	21.0 (4.7)	11.7 (3.5)	26.0 (5.2)	4.3 (2.3)	10.4 (3.4)	9.5 (3.2)	6.6 (2.8)	10.1 (3.3)	9.8 (3.3)
Atrazine 1.5 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS	17.3 (4.3)	10.7 (3.4)	8.7 (3.1)	21.7 (4.8)	10.7 (3.4)	14.0 (3.9)	3.5 (2.1)	9.3 (3.2)	7.5 (2.9)	5.5 (2.5)	9.0 (3.1)	7.9 (3.0)
Halosulfuron 90 g/ha at 25 DAS	9.3 (3.2)	8.0 (3.0)	10.3 (3.4)	13.7 (3.8)	7.3 (2.8)	16.0 (4.1)	1.5 (1.6)	5.0 (2.4)	6.9 (2.8)	3.5 (2.1)	4.7 (2.4)	7.2 (2.9)
Atrazine 1.5 kg/ha as pre-emergence *fb* halosulfuron 90 g/ha at 25 DAS	7.0 (2.8)	7.0 (2.8)	8.3 (3.0)	11.3 (3.5)	6.7 (2.7)	12.3 (3.6)	1.3 (1.5)	4.5 (2.3)	6.4 (2.7)	3.3 (2.1)	4.1 (2.3)	6.7 (2.8)
Tembotrione 120 g/ha at 25 DAS	18.0 (4.3)	6.3 (2.7)	8.7 (3.1)	22.3 (4.8)	7.3 (2.8)	14.3 (3.9)	2.3 (1.8)	5.1 (2.4)	8.6 (3.1)	4.4 (2.3)	4.4 (2.3)	8.9 (3.1)
Pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS	8.3 (3.0)	6.0 (2.6)	12.3 (3.6)	13.0 (3.7)	6.7 (2.7)	18.3 (4.4)	2.6 (1.9)	4.7 (2.3)	10.4 (3.4)	4.7 (2.4)	4.1 (2.2)	10.7 (3.4)
Atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha at 25 DAS	9.0 (3.2)	5.0 (2.4)	7.7 (2.9)	13.7 (3.8)	5.3 (2.5)	13.0 (3.7)	1.7 (1.6)	3.3 (2.1)	7.1 (2.8)	3.8 (2.2)	3.3 (2.1)	7.4 (2.9)
Control (weedy check)	62.0 (7.9)	32.0 (5.7)	53.0 (7.3)	63.0 (8.0)	29.3 (5.5)	54.3 (7.4)	20.5 (4.6)	20.9 (4.7)	18.1 (4.4)	22.8 (4.9)	20.5 (4.6)	19.4 (4.5)
Weed free	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)
LSD(p=0.05)	0.74	0.71	0.49	0.74	0.91	0.59	0.38	0.64	0.31	0.35	0.49	2.52

Values in the parentheses are original values and are subject to square root transformation

With respect to sedges, application of atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha as PoE recorded significantly the lesser weed count (2.9 and 3.7 no/m^2) on 50 DAS and it was comparable with application of atrazine 1.5 kg/ha as PE *fb* halosulfuron 90 g/ha at 25 DAS (3.0 and 3.6 no./m^2), tembotrione 120 g/ha as PoE (3.1 and 3.9 no./m^2), atrazine 1.5 kg/ ha + 2,4-D amine 0.4 kg/ha as PoE (3.1 and 3.9 no./ m^2), halosulfuron 90 g/ha at 25 DAS (3.4 and 4.1 no./ m^2). Significantly lesser weed dry weight (2.7 and 2.8 g/m^2) recorded with the application of atrazine 1.5 kg/ ha as PE *fb* halosulfuron 90 g/ha at 25 DAS as compared to atrazine 1.5 kg/ha as PE (3.3 and 3.4 g/ m^2), atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha as pre-emergence (3.2 and 3.3 g/m^2) and treatment pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS as PoE (3.4 g/m^2 each) during the years 2016 and 2017, respectively.

Effect of herbicides on weed control efficiency and weed index

Weed control efficiency (WCE) varied with different weed control methods at 50 DAS (**Table 2**). In WCE, total weed dry weight was taken into account which consisted of different weed species with varying proportions. WCE do not effect the individual weed species effect. Performance of crop is directly proportional to the WCE and inversely proportional to the weed index. At 50 DAS, the maximum WCE of grasses and sedges weeds were recorded with the application of atrazine 1.5 kg/ha as PE *fb* halosulfuron 90 g/ha at 25 DAS (93.7 and 85.5%) and (64.6 and 65.5%) followed by halosulfuron 90 g/ha at 25 DAS (92.7 and 84.6%) and (61.9 and 62.9%), and atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha as PoE (91.7 and 83.3%) and (60.8 and 61.9%) respectively, during 2016 and 2017. In broad-leaf weeds higher WCE was recorded with the application of atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha as PoE (84.2 and 83.9%) But lesser WCE was recorded with the application of atrazine 1.5 kg/ha as PE (41.1 and 43.4%) during 2016 and 2017. It was due to lower weed population and total dry weight of weeds in these treatments due to better control of weeds following exposure to PoE application of herbicides Hatti *et al.* (2014) and Sah *et al.* (2015)

Weed index data computed on the basis of maximum grain yield as (**Table 2**) it showed that un-weeded control recorded the maximum yield loss of 45.5 and 34.7% during 2016 and 2017, respectively. Minimum yield loss were observed in treatments pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS (4.9 and 3.9%) and atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha at 25 DAS (5.6 and 4.4%) as compared to the all other treatments. Slow growth of crop in the early stages offered much scope for the development of weeds beside the competitiveness of weeds in utilizing the resources which resulted in more loss of yield Patel *et al.* (2006). This clearly indicated that the sequential use of PE herbicides followed PoE spray at 25 DAS was the most effective approach in controlling weeds and thus resulted in recording significantly lower values for weed index. These findings were in conformity with the findings of Sreenivas *et al.* (1992) and Hawaldar and Agasimani (2012).

Effect of herbicides on growth and yield of maize

A comparatively lesser number of plants per hectare was recorded in the weed check (control) treatment but it did not bring a significant difference in plant population than all other treatments during both the years. Weed control treatments brought about significant variation in cobs per hectare. Significantly lesser number of cobs per hectare were recorded in treatment weedy check (70.8 and 73.1 x 10^3 /ha) and all the treatments, however, it was statistically at par with treatment atrazine 1.5 kg/ha as PE (74.8 and 77.8 x 10^3 /ha) and treatment halosulfuron 90 g/ha at 25 DAS (74.5 and 74.8 x 10^3 /ha) during 2016 and 2017, respectively **Table 3**. Weed-free condition recorded higher plant height

Table 2. Weed control efficiency and weed index as affected by pre and post-emergence herbicides of *kharif* maize

Treatment	Weed control efficiency (%)						Weed index (%)	
	2016			2017				
	Grasses	Broad-leaf	Sedges	Grasses	Broad-leaf	Sedges	2016	2017
Atrazine 1.5 kg/ha as pre-emergence (PE)	70.7	41.1	44.2	63.6	43.4	46.4	30.1	27.2
Atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha as PE	79.0	50.2	47.5	71.1	50.7	49.5	9.3	10.9
Atrazine 1.5 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS	82.9	55.5	58.6	75.9	56.1	59.3	22.6	22.8
Halosulfuron 90 g/ha at 25 DAS	92.7	76.1	61.9	84.6	77.1	62.9	27.8	26.7
Atrazine 1.5 kg/ha as PE *fb* halosulfuron 90 g/ha at 25 DAS	93.7	78.5	64.6	85.5	80.0	65.5	12.1	16.6
Tembotrione 120 g/ha at 25 DAS	88.8	75.6	52.5	80.7	78.5	54.1	14.5	19.9
Pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS	87.3	77.5	42.5	79.4	80.0	44.8	4.9	3.9
Atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha at 25 DAS	91.7	84.2	60.8	83.3	83.9	61.9	5.6	4.4
Control (weedy check)	-	-	-	-	-	-	45.5	34.7

Table 3. Effect of pre- and post-emergence herbicides on growth and yield of *Kharif* maize

Treatment	Plants ($x10^3$ `/ha)		Cobs ($x10^3$ `/ha)		Plant height (cm)		Days to 50% tasseling		Days to 50% silking		Grain yield (t/ha)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Atrazine 1.5 kg/ha as pre-emergence (PE)	79.9	78.9	74.8	77.8	198.3	202.3	60.0	57.7	61.7	59.7	4.69	4.85
Atrazine 0.75kg/ha + pendimethalin 0.75 kg/ha as PE	81.7	80.6	79.2	79.4	205.3	209.3	60.7	58.3	62.7	60.3	6.09	5.94
Atrazine 1.5 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS	81.3	79.2	77.1	78.5	194.0	198.0	60.7	58.3	62.3	60.7	5.19	5.15
Halosulfuron 90 g/ha at 25 DAS	80.3	75.7	74.5	74.8	180.3	184.3	61.0	58.7	63.3	61.0	4.84	4.89
Atrazine 1.5 kg/ha as PE *fb* halosulfuron 90 g/ha at 25 DAS	81.7	79.4	77.8	78.0	183.3	187.3	61.3	59.0	63.7	61.7	5.90	5.56
Tembotrione 120g/ha at 25 DAS	80.8	78.9	77.5	78.0	197.7	201.7	59.7	57.3	61.7	59.7	5.74	5.34
Pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS	81.9	81.7	80.8	80.8	201.7	205.7	60.0	57.7	61.3	59.3	6.38	6.41
Atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha at 25 DAS	82.2	81.5	80.6	81.5	202.3	206.7	59.7	57.3	61.0	59.7	6.34	6.37
Control (weedy check)	80.6	76.4	70.8	73.1	161.3	163.3	61.7	60.0	64.3	62.3	3.66	4.35
Weed free	82.6	82.4	81.5	81.7	215.3	219.3	59.7	57.3	61.0	59.3	6.71	6.67
LSD (p=0.05)	NS	NS	4.4	5.0	27.2	197.8	NS	NS	1.8	1.8	0.84	0.94

(215.3 and 219.3 cm) as compared to treatments halosulfuron 90 g/ha at 25 DAS (180.3 and 184.3 cm), atrazine 1.5 kg/ha PE *fb* halosulfuron 90 g/ha at 25 DAS (183.3 and 187.3 cm) and weedy check (161.3 and 163.3 cm) and it was statistically at par with all other treatments during 2016 and 2017. The different weed management practices failed to exert any significant effect on days taken to 50% tasseling. Significantly more number of days taken to 50% silking was recorded with the weedy check treatment (64.3 and 62.3) as compared to all other treatments. However, it was statically at par with atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha as PE (62.7), halosulfuron 90 g/ha at 25 DAS (63.3), atrazine 1.5 kg/ha as PE *fb* halosulfuron 90 g/ha at 25 DAS (63.7) during 2016 and atrazine 1.5 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS as PoE (60.7), halosulfuron 90 g/ha at 25 DAS (61.0) and atrazine 1.5 kg/ha as PE *fb* halosulfuron 90 g/ha at 25 DAS (61.7) during 2017.

Weed-free condition recorded significantly higher grain yield 6.71 t/ha and 6.67 t/ha, during both the years, but it was statistically at with the application of pendimethalin 1.0 kg/ha as PE *fb* atrazine 0.75 kg/ha + 2,4-D amine 0.4 kg/ha at 25 DAS as PoE (6.38 and 6.41 t/ha), atrazine 1.5 kg/ha as PE *fb* tembotrione 120 g/ha as PoE (6.34 and 6.37 t/ha) and atrazine 0.75 kg/ha + pendimethalin 0.75 kg/ha as PE(6.09 and 5.94 t/ha). The highest grain yield obtained under weed-free condition was mainly due to minimum crop-weed competition throughout the crop growth period, thus enabling the crop for maximum utilization of nutrients, moisture, light, and space, which favoured growth and yield components. Similar results have also been observed by Hatti *et al.* (2014) and Triveni *et al.* (2017).

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Weed dynamics, growth pattern, yield and economics of linseed under different weed management practices

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ABSTRACT

A field experiment was conducted during *Rabi* season of 2016-17 and 2017-18 at Research cum Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh to study weed dynamics, growth pattern, yield and economics of Linseed (*Linum usitatissimum* L.) under weed management practices. The experiment consisted ten treatments replicated thrice using the linseed variety '*RLC-92*'.The plant population, plant height and number of branches varied significantly among different weed management treatments. Linseed seed yield was significantly higher (1.94 t/ha) with hand weeding twice, which was statistically at par with isoproturon + metsulfuron-methyl (1 kg + 4 g/ ha) post-emergence treatment (PoE), metsulfuron-methyl (4 g/ha) PoE and pendimethalin (1 kg/ha) pre-emergence treatment (PE) followed by (*fb)* metsulfuron-methyl (4 g/ha) PoE. Density and biomass of weed was the lowest and weed control efficiency was higher with hand weeding twice 21 and 45 days after seeding (DAS) followed by isoproturon + metsulfuron-methyl (1 kg + 4 g/ ha) PoE and metsulfuron-methyl (4 g/ha) PoE. The gross return was maximum with hand weeding twice 21 and 45 DAS while net return was maximum with isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) PoE. The highest benefit: cost ratio (3.91) was recorded with metsulfuron-methyl (4 g/ha) PoE due to higher seed yield coupled with lower cost of chemical treatment.

INTRODUCTION

India is an important linseed growing country in the world and it contributes 7% to the world linseed pool (Devendra *et al.* 2016). Among the oilseeds, linseed or flax (*Linum usitatissimum* L.) is one of the oldest crop, grown in almost all countries of world for oil, fibre and seed purpose. Linseed is unique among oilseeds for its technical grade vegetable oil producing ability and fibre (good quality having high strength and durability) production. Linseed contains 35-45% oil with high content of omega-3 fatty acid and alpha lenolenic acid (ALA). Omega-3 fatty acid lowers levels of triglycerides in the blood, thereby reducing heart disease and also promise in the battle against rheumatoid arthritis (Amin and Thakur 2014, ISOR 2015). Linseed oil contains three times as much omega-3 fatty acid than omega-6 fatty acid (Singh *et al.* 2013). Its seed has 36% protein out of which 85% is digestible. Its oil cake is used to feed milch and fattening animals for milk and meat production. Its oil has a lot of uses apart from human consumption *viz.* Oil paint, varnishes, printing ink, oil cloth, soap, patent leather and waterproof fabrics due to its fast volatility feature (Sharma *et al.* 2015). Round the globe linseed crop occupies an area of 2.764 million ha yielding out 2.925 million tons having an average productivity of 1.06 t/ha (Anonymous 2018). Our national production of 0.18 million tons is realized from an area of 0.32 million/ha with low productivity of 567 kg/ha in world arena (Anonymous 2017a).

Linseed is mainly cultivated in the states like Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Maharashtra, Rajasthan, West Bengal, Karnataka, Odisha and Bihar. The average productivity of this crop is very low as compared to other oilseed crops, which can be attributed to several reasons. The major causes behind low production of linseed mainly in sub-marginal and input starved coupled with poor weed management (Anonymous 2017b). Hence appropriate herbicides for managing weeds in linseed are needed for enhancing linseed yield. Pre-mixed application of pre-emergence and post-emergence herbicides was found effective elsewhere for weed control in linseed and other oilseed crops (Siddesh *et al.* 2016) but region specific information is needed. Therefore the study was carried out to evaluate herbicides for weed dynamics, growth pattern, yield and economic in linseed.

MATERIALS AND METHODS

Experiment was conducted at Research cum Instructional Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, (C.G.) during *Rabi* season of 2016-17 and 2017-18. The experiment was conducted in a randomized block design with ten treatments replicated thrice. The treatment details were: metribuzin + oxyflurofen (250 g + 125 g/ha) pre-emergence treatment (PE), oxyflurofen (25 g/ha) PE, oxadiargyl (80 g/ha) PE, imazethapyr (75 g/ha) post-emergence treatment (PoE), metsulfuron-methyl (4 g/ha) PoE, isoproturon (1 kg/ha) PoE, isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) PoE, pendimethalin (1 kg/ha) PE *fb* metsulfuron-methyl (4 g/ha) PoE, hand weeding twice 21 and 45 days after seeding (DAS) and weedy check. Linseed variety '*RLC-92*'was sown on 19th November 2016 and 15th November 2017, first year and second year respectively at 30 cm row to row spacing. Observations for crop and weed were determined as per standard procedure. The computation of weed control efficiency and economics study *i.e.* cost of cultivation, gross return, net return and B:C ratio were computed as per standard formulas. Pooled data of 2 years has been presented in this paper. Transformation ($\sqrt{x + 0.5}$) of weed data and statistical analysis was fallowed as per Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on growth and yield of linseed

Seed yield is highly dependent upon the growth and yield attributes of linseed crop. The significantly higher plant population was observed with isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) PoE, which was found at par with the treatment of metsulfuron-methyl (4 g/ha) POE, pendimethalin (1 kg/ha) PE *fb* metsulfuron-methyl (4 g/ha) PoE and hand weeding twice at 21 and 45 DAS and lower plant population recorded under weedy check treatment at both stages of observations, as reported earlier (Bali *et al*. 2015). The maximum plant height was observed with hand weeding twice at 21 and 45 DAS at all growth stages of linseed (**Table 1**). Maximum number of branches was found with hand weeding twice at 21 and 45 DAS at harvest stage and statistically at par with the application of isoproturon + metsulfuron-methyl (1 kg/ha + 4 g/ha) PoE, metsulfuron-methyl (4 g/ha) PoE and pendimethalin (1 kg/ha) PE *fb* metsulfuron-methyl (4 g/ha) PoE. At 30 DAS differences were not significant among weed management practices as reported by Mankar (2015). Significantly higher seed yield (1.94 t/ha) was observed with hand weeding twice and it was statistically at par with isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) PoE, metsulfuron-methyl (4 g/ha) PoE and pendimethalin (1 kg/ha) PE *fb* metsulfuron-methyl (4 g/ha) PoE. Minimum seed yield was recorded under weedy check due to unhindered weed growth. Similar findings were also reported by Dange *et al.* **(**2007**)** and Jain and Agarwal (1998).

Effect on weeds

The weed density and biomass of *Medicago denticulata*, *Convolvulus arvensis*, *Parthenium hysterophorus* and others were recorded at 30 and 60 DAS (**Table 2**). The weed density and biomass were significantly influenced by different weed

Table 1. Effect of weed management treatments on linseed growth parameters and yield

Treatment	Plant population (no./m^2)		Plant height (cm)				No. of branches/plant		Yield (t/ha)
	Initial	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	At harvest	
Metribuzin + oxyfluorfen (250 g + 125 g/ha) 1 DAS	173	165	14.2	62.6	68.6	69.6	2.5	3.6	1.71
Oxyflurofen (125 g/ha) 1 DAS	171	164	13.9	62.3	68.2	69.3	2.4	3.5	1.65
Oxadiargyl (80 g/ha) 1 DAS	168	161	13.6	61.7	67.9	69.2	2.3	3.6	1.61
Imazethapyr (75 g/ha) 22 DAS	163	155	13.8	61.4	67.7	68.8	2.5	3.5	1.49
Metsulfuron-methyl (4 g/ha) 22 DAS	205	196	15.3	64.7	70.8	71.8	2.8	3.9	1.87
Isoproturon (1 kg/ha) 22 DAS	195	187	14.9	63.7	69.8	70.4	2.6	3.7	1.81
Isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) 22 DAS	207	199	15.9	66.3	72.7	74.1	2.8	4.0	1.92
Pendimethalin (1 kg/ha) 1 DAS *fb* metsulfuron-methyl (4 g/ha) 22 DAS	201	192	15.0	64.4	70.4	71.3	2.6	3.8	1.83
Hand weeding twice 21 and 45 DAS	207	199	16.4	67.5	74.7	75.7	2.6	4.2	1.94
Weedy check	162	155	14.2	61.3	67.8	68.7	2.6	3.4	1.37
LSD (p=0.05)	8.03	8.63	1.49	3.62	4.22	4.36	NS	0.40	0.12

DAS = Days after seeding; *fb* = followed by management treatments. At 30 and 60 DAS minimum weed density and biomass were observed with hand weeding twice, and it was on par with pendimethalin (1 kg/ha) PE *fb* metsulfuron-methyl (4 g/ha) PoE and metribuzin + oxyflurofen (250 g + 125 g/ha) PE at 30 DAS except *Parthenium hysterophorus*. However, at 60 DAS application of isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) PoE and metsulfuron-methyl (4 g/ha) PoE was found at par value of weed density and biomass. Maximum weed density and biomass were recorded in weedy check.These results are corroborative with the findings of Malligwad *et al.* (2000) and Madhu *et al. (*2006).

At 30 and 60 DAS, highest weed control efficiency (**Table 4**) was found with hand weeding twice at 21 and 45 DAS and it was at par with pendimethalin (1 kg/ha) PE *fb* metsulfuron-methyl (4 g/ha) PoE and isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) PoE at 30 and 60 DAS respectively and minimum was observed with the application of imazethapyr (75 g/ha) PoE. These results were in close conformity with Kapur and Singh (1992).

Effect on economics

The highest cost of cultivation and gross return was recorded with hand weeding twice at 21 and 45 DAS due to higher cost involved in labour wages, followed by the treatment of isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) PoE (**Table 4**). The highest net return was noted under isoproturon +

Table 2. Effect of weed management treatments on individual weed density in linseed

Treatment	Weeds density (no./m^2)							
	M.denticulata		*C.arvensis*		*P.hysterophorus*		Other weeds	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Metribuzin + oxyfluorfen (250 g + 125 g/ha) 1 DAS	3.71(13.4)	3.85(14.3)	1.72(2.5)	1.91(3.2)	1.47(1.7)	1.62(2.2)	2.24(4.5)	2.67(6.7)
Oxyflurofen (125 g/ha) 1 DAS	4.28(17.8)	5.45(29.3)	1.82(2.8)	2.07(3.8)	1.53(1.8)	1.78(2.7)	2.34(5.2)	2.84(7.7)
Oxadiargyl (80 g/ha) 1 DAS	4.58(20.8)	6.13(37.2)	1.90(3.2)	2.15(4.2)	1.69(2.5)	1.91(3.2)	2.53(6.0)	2.99(8.5)
Imazethapyr (75 g/ha) 22 DAS	7.16(51.0)	7.56(56.8)	2.35(5.0)	2.24(4.7)	2.07(4.0)	2.00(3.5)	3.08(9.2)	3.13(9.3)
Metsulfuron-methyl (4 g/ha) 22 DAS	6.92(47.4)	1.85(3.0)	2.19(4.3)	1.38(1.5)	2.08(3.4)	1.28(1.2)	2.92(8.3)	1.99(3.5)
Isoproturon (1 kg/ha) 22 DAS	5.44(29.2)	2.79(7.3)	2.04(3.7)	1.67(2.3)	1.77(2.7)	1.53(2.0)	2.81(7.5)	2.54(6.0)
Isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) 22 DAS	6.47(41.3)	1.63(2.2)	2.12(4.0)	1.35(1.3)	2.04(3.7)	1.07(0.7)	2.91(8.0)	1.72(2.7)
Pendimethalin (1 kg/ha) 1 DAS *fb* metsulfuron-methyl (4 g/ha) 22 DAS	3.35(10.7)	2.51(5.8)	1.73(2.5)	1.46(1.7)	1.28(1.3)	1.44(1.7)	1.89(3.2)	2.13(4.5)
Hand weeding twice 21 and 45 DAS	1.46(1.7)	1.41(1.5)	0.90(0.3)	0.90(0.3)	0.90(0.3)	0.80(0.2)	0.98(0.5)	0.80(0.2)
Weedy check	8.17(66.3)	7.93(62.3)	2.45(5.5)	2.37(5.3)	2.33(5.0)	2.08(3.8)	3.40(11.2	3.58(12.3
LSD (p=0.05)	0.55	0.52	0.34	0.39	0.48	0.40	0.50	0.64

Figures in parentheses are original, transformed to values $\sqrt{x+0.5}$; *DAS = Days after seeding; *fb* = followed by

Table 3. Effect of weed management treatments on individual weeds biomass in linseed

Treatment	Weeds biomass (g/m^2)							
	M.denticulata		*C. arvensis*		*P.hysterophorus*		Other weeds	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Metribuzin + oxyfluorfen (250 g + 125 g/ha) 1 DAS	2.46(2.2)	3.07(9.0)	1.08(0.7)	1.57(2.0)	1.00(0.5)	2.16(4.2)	1.25(1.1)	3.57(12.4)
Oxyflurofen (125 g/ha) 1 DAS	2.66(2.7)	4.13(16.7)	1.11(0.7)	1.92(3.2)	1.05(0.6)	2.17(4.2)	1.34(1.3)	3.98(15.3)
Oxadiargyl (80 g/ha) 1 DAS	2.70(3.9)	4.54(20.1)	1.15(0.8)	2.06(3.8)	1.02(0.6)	2.43(5.4)	1.30(1.2)	4.12(16.5)
Imazethapyr (75 g/ha) 22 DAS	3.37(7.0)	5.06(25.3)	1.35(1.3)	2.11(4.0)	1.14(0.8)	2.62(6.4)	1.47(1.7)	4.26(17.6)
Metsulfuron-methyl (4 g/ha) 22 DAS	3.35(6.6)	2.05(3.7)	1.27(1.1)	1.18(0.9)	1.15(0.8)	1.69(2.4)	1.45(1.6)	2.65(6.6)
Isoproturon (1 kg/ha) 22 DAS	2.97(4.9)	2.34(5.0)	1.22(1.0)	1.41(1.5)	1.07(0.7)	2.15(4.1)	1.44(1.6)	3.34(10.8)
Isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) 22 DAS	3.25(5.3)	1.72(2.0)	1.26(1.1)	1.24(1.1)	1.23(1.0)	1.06(0.7)	1.53(1.9)	2.29(5.2)
Pendimethalin (1 kg/ha) 1 DAS *fb* metsulfuron-methyl (4 g/ha) 22 DAS	2.40(1.7)	2.24(4.5)	1.06(0.6)	1.29(1.2)	0.96(0.5)	1.99(3.7)	1.11(0.8)	2.69(7.4)
Hand weeding twice 21 and 45 DAS	1.64(0.1)	1.51(1.8)	0.77(0.1)	1.03(0.6)	0.76(0.1)	0.80(0.1)	0.76(0.1)	1.00(0.7)
Weedy check	3.62(8.9)	5.37(28.4)	1.42(1.5)	2.21(4.5)	1.27(1.1)	2.78(7.2)	1.67(2.4)	4.60(20.7)
LSD (p=0.05)	0.37	0.37	0.16	0.35	0.20	0.51	0.29	0.88

Figures in parentheses are original, transformed to values $\sqrt{x+0.5}$; *DAS = Days after seeding; *fb* = followed by

Table 4. Effect of weed management treatments on cost of cultivation and weed control efficiency of linseed

Treatment	Cost of Cultivation ($x10^3$ `/ha)	Gross returns ($x10^3$ `/ha)	NMR ($x10^3$ `/ha)	B:C ratio	Weed control efficiency (%)	
					30 DAS	60 DAS
Metribuzin + oxyfluorfen (250 g + 125 g/ha) 1 DAS	20.03	77.50	57.46	3.37	68.69	54.52
Oxyflurofen (125 g/ha) 1 DAS	19.60	74.70	55.10	3.31	61.82	35.13
Oxadiargyl (80 g/ha) 1 DAS	19.80	73.17	53.38	3.20	53.75	24.64
Imazethapyr (75 g/ha) 22 DAS	19.67	67.56	47.89	2.94	22.58	12.55
Metsulfuron-methyl (4 g/ha) 22 DAS	19.27	84.96	65.69	3.91	27.28	77.58
Isoproturon (1 kg/ha) 22 DAS	20.36	82.34	61.98	3.55	41.94	64.70
Isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) 22 DAS	20.63	87.31	66.68	3.73	33.27	84.59
Pendimethalin (1 kg/ha) 1 DAS *fb* metsulfuron-methyl (4 g/ha) 22 DAS	20.33	82.97	62.64	3.58	74.59	72.37
Hand weeding twice 21 and 45 DAS	22.80	88.17	65.37	3.37	97.28	94.71
Weedy check	18.80	62.25	43.45	2.82	0	0

*DAS = Days after seeding; *fb* = followed by; NMR = Net monetary return

metsulfuron-methyl (1 kg + 4 g/ha) PoE, followed by metsulfuron-methyl (4 g/ha) PoE and hand weeding twice at 21 and 45 DAS. The highest benefit: cost ratio (3.91) was recorded with metsulfuron-methyl (4 g/ha) PoE followed by isoproturon + metsulfuron-methyl (1 kg + 4 g/ha) PoE and pendimethalin (1 kg/ha) PE *fb* metsulfuron-methyl (4 g/ha) PoE. The higher B:C ratio in above treatments might be due to higher seed yield coupled with lower cost of the treatment. Similar finding was reported by Mishra *et al.* (2003).

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Terpenoid from essential oil of *Cyperus scariosus* and its biological activity on chilli

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ABSTRACT

Allelopathic effect of the essential oil of wild sedge- *Cyperus scariosus*, it's polar and non-polar fractions, isolated compound-cyprene and its derivatives: cyprene epoxide and cyprene alcohol were screened for germination studies on chilli (*Capsicum annuum* L.). Chilli is a vegetable crop in Punjab which is having trouble shooting problem during its germination stage, which leads to the interruption in growth curve of the seedling. Treatment of seeds with oil, its fractions and its derivatives lead to stimulatory effect (approx. 75-100%) in terms of primary root and shoot length with collateral increase in dry and fresh weight of seedlings over control at 20 days. Oil and its polar fraction found to be the most effective in enhancing the root length and shoot length, and acts as potent plant growth regulator at the concentration of 0.5 µg/mL.

INTRODUCTION

Cyperus scariosus (Syn. *Cyperus pertenius* Roxb.) known as Cypirol is an invasive weed belongs to family *Cyperaceae* with angular soft stem (40-90 cm), underground rhizomatous tubers, pestiferous perennial, medicinal plant of height 45-75 cm approximately (Srivastava *et al.* 2014). It is commonly known as *Nagarmotha*, and is widely distributed in the forest and swamp areas of tropical and temperate regions of the world (Kasana *et al.* 2013). It is a noxious weed adversely effecting more than 30 crops in 92 countries (Srivastava *et al.* 2014). The weed grows rapidly and fills the soil with its tangle of roots and rhizomes which interfere in the growth of various crops. The presence of chemical constituents such as steroids, alkaloids, terpenoids, saponins, gums, lactones, coumarin, essential oils and esters etc. in *Nagarmotha*, make this weed of immense interest for potential application in various fields (Utreja *et al.* 2015). The essential oil and its various components of weed are known to possess antibacterial, antimicrobial, antifungal, analgesic and antidiabetic, hypotensive, spasmolytic and plant growth regulator activities.

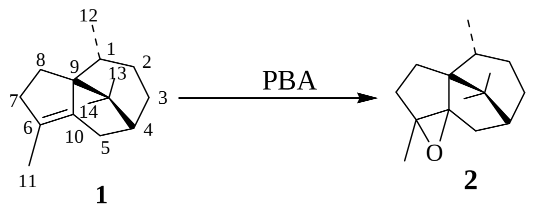
Chilli is an annual herbaceous vegetable crop which belongs to nightshade family Solanaceae. The yield of chilli is very low in third world countries due to lack of good stand establishment and reduced early growth due to adverse environment conditions. Chilli has non-starchy endosperm which offers mechanical barrier to growing embryo resulting in poor germination (Andreoli and Khan 1999, Belakbir *et al.* 1998, Lim *et al.* 2009, Margarita *et al.* 2015). High germination and uniform stand establishment in chilli is essential for profitable yields (Khan *et al.* 2012). It has been found that seed performance of many vegetables can be improved by doing various pre-sowing treatments (Ashraf and Foolad 2005), which may enhance uniform germination, normal and vigorous seedlings resulting in fast and higher rate of germination and emergence (Farooq *et al.* 2007).

Literature citations have shown the positive effects of essential oil of Cypirol and its components as potent plant growth regulator (PGRs) in mung beans (Kalsi *et al.* 1980), grapevine cuttings (Kaur *et al.* 2002), wheat (Sharma *et al.* 2016) and sprouting in sugarcane cuttings (Talwar *et al.* 1999). Therefore, the study was established to evaluate the germination studies of essential oil of *C. scariosus*, it's polar and non-polar fractions, isolated compound-cyprene and its derivatives: cyprene epoxide and cyprene alcohol in chilli.

MATERIALS AND METHODS

C. scariosus oil was subjected to column chromatography to isolate it into non-polar (hexane) and polar fractions (dichloromethane). During column chromatography of oil using hexane as solvent, the non-polar fraction was collected and was distilled with the help of distillation set. Thin layer chromatography (TLC) of compound obtained after distillation from the non-polar fraction was carried out. Silver-nitrate impregnated chromatoplates gave one major spot having R_f = 0.95 and the compound was identified as cyprene **1** on the basis of spectral analysis (Trivedi *et al.* 1964). Epoxidation of cyprene **1** into cyprene epoxide **2** was achieved by using perbenzoic acid (PBA) (Scheme i) and was confirmed with spectral analysis (Sharma *et al.* 2016).

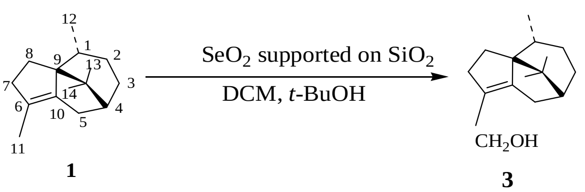
Scheme i: Synthesis of cyprene epoxide **2** from cyprene **1**



1 **2**

Selective oxidation of allylic methyl of cyprene **1** was carried out using selenium dioxide with *t*-butyl hydroperoxide (TBHP) and resulted in the formation of oxidized product cyprene alcohol **3**. In the oxidation procedure selenium dioxide (SeO_2) (2.5 g) was dissolved in minimum quantity of distilled water and volume was raised to 75 mL by addition of methanol to get clear solution. To this clear solution, 50 g of silica gel (60-120 mesh size) was added and was evaporated under reduced pressure to furnish free flowing powder. To selenium dioxide supported on silica gel (0.5 g), dichloromethane (5 mL) and TBHP (3 mL) were added and reaction mixture was stirred for 15 min at room temperature (Scheme ii). To this reaction mixture, dropwise addition of cyprene (1 g) was made and the reaction mixture was allowed to stir at room temperature until the completion of reaction (48 h, TLC). After completion, reaction mixture was filtered and residue was washed with dichloromethane. The filtrate and washings were combined, washed with water, brine, dried over sodium sulfate and evaporation under reduced pressure with rotary evaporator pump, afforded cyprene alcohol **3**. During the reaction procedure the major product was cyprene alcohol (Chhabra and Hayano 1981).

Scheme ii: Synthesis of cyprene alcohol **3** from cyprene **1**



1 **3**

Cyprene alcohol (spectral studies)

IR (KBr): 1382, 1372, 3078, 2953, 3360 cm^{-1}.

^1H NMR (400 MHz, $CDCl_3$): 1.40 (s, C13-Me), 2.32 (s, C14-Me), 1.23 (d, *J* = 9.2Hz), 4.97 (s, C11- CH_2 attached to –OH group), 8.22 (-OH group)

^{13}C NMR (100 MHz DMSO-d_6): 21.45, 21.95, 25.50, 25.79, 26.40, 26.50, 26.62, 26.82, 29.72, 31.01, 80.96, 135.91, 137.89 ppm.

Products yield: 60%

(s = Singlet, d = doublet, ppm = parts per million, Hz = Hertz and *J* is coupling constant)

The stock solutions (2000 µg/mL) of oil, its polar and non-polar fraction, cyprene **1**, cyprene epoxide **2**, cyprene alcohol **3** were prepared by dissolving each compound (20 mg) in 1 mL of Tween 20 (Polyoxyethylene sorbitan) and volume was made 10 mL with distilled water. The stock solution of 2000 µg/mL of each compound thus prepared on active ingredient basis and was kept in refrigerator till use. The required dilutions of 100, 75, 50, 25, 20, 15, 10, 5, 2.5, 1, 0.5 µg/mL were subsequently made from the stock solution by adding distilled water as and when required.

Chilli seeds were obtained from the Department of Vegetable Sciences, Punjab Agricultural University, Ludhiana. Ten homogenous seeds were plated per Petri-dish (9 cm) lined with Whatman filter paper (pure cellulose paper) and moistened with solutions of the oil, polar fraction, non-polar fraction, cyprene and cyprene alcohol at different concentrations (0.5–100 µg/mL) along with distilled water as control. 6 mL solution of each compound was poured in each Petri plate regularly to soak seeds. The seeds were not let dry and the experiment was replicated thrice for each treatment. The Petri-dishes containing seeds were incubated at 28±2 ^{0}C and were observed daily for twenty days for germination. Germinated seeds were observed and counted daily. The appearance of 2 mm or more of radicle was considered as germination and germination percentage was calculated as follow:

Germination percentage (GP) = (Total germinated seed/ total number of seed) x 100

The morphological characters such as root length and shoot length were measured at the end of twenty days after plating with a graduated meter. At the end of twenty days, fresh weight of seedlings was recorded and then the seedlings were oven dried at 60 ^{0}C for 3 days for their dry matter content. Various morphological parameters of chilli recorded in distilled water as control were root length (1.5 cm), shoot length (2.3 cm), fresh weight (22 mg) and dry weight (9 mg). Shoot length was measured from the base till tip of the uppermost leaf. Root length was measured from the base till tip of the longest root.

The results of the enhancement of the plant growth were calculated in the terms of seedling vigour index.

Seedling vigour index = % germination × total seedling dry weight

The statistical analysis for the plant growth regulator activity of the oil, its polar and non-polar fractions, isolated compounds cyprene **1** and its derivatives cyprene epoxide **2**, cyprene alcohol **3** was carried out on seedlings of chilli. The compounds (A), concentrations (B) and their interactions were studied statistically by Factorial CRD and Tukey's test to study the extent of dependency of concentrations and compounds and their effect on enhancement of root length, shoot length, fresh weight, dry weight and seedling vigour index of chilli seedlings.

The seedling growth parameters *viz.* root length and shoot length, fresh and dry weight were recorded at the end of 20 days after placing the seeds for germination.

RESULTS AND DISCUSSION

The seeds treated with polar fraction concentrations (0.5 µg/mL) showed 100% germination, which also initiated early germination. In other test fractions, higher germination percentage (75%) was observed when treated with more than 2.5 µg/mL concentration. The number of roots were found to be four or five in the *C. scariosus* oil at each concentration. But in case of other compounds only two or three roots were observed. In control, only one root was observed. Therefore, *C. scariosus* oil was effective in growth of secondary roots.

Both shoot and root length, significantly increased with the increase in concentration of each compound. Polar fraction was found to be most active in enhancing shoot length (**Table 1**) and it was found that there is significant interaction between A and B. All the compounds showed significantly different activity with respect to each other but the activity of Cyprene **1** was found to be at par with non-polar fraction (**Table 6 and 7**).

C. scariosus oil was found to be the most active in enhancing root length (**Table 2**). But in root length analysis, there was significant interaction between A and B, all compounds showed significantly variant activity from each other. Cyprene **1**, cyprene epoxide **2**, cyprene alcohol **3**, and non-polar fraction also showed potential in enhancing the shoot and root length of the seedlings.

Table 1. Effect of oil and its components on shoot length (cm)

Conc. (µg/mL)	Oil	Non-polar	Polar	Cyprene	Cyprene epoxide	Cyprene alcohol
0.5	1.46	0.96	1.70	1.06	1.43	1.60
1.0	1.93	1.13	2.00	1.30	1.53	1.80
2.0	2.03	1.20	2.36	1.30	1.53	2.20
2.5	2.10	1.43	2.60	1.53	1.86	2.40
5.0	2.26	1.50	2.90	1.60	2.00	2.70
10.0	2.20	1.50	3.13	1.90	2.20	2.70
20.0	2.50	1.60	3.80	2.00	2.30	3.00
25.0	2.60	1.80	4.00	2.10	2.40	3.20
50.0	3.10	2.10	4.90	2.40	2.60	3.90
75.0	3.20	2.30	5.90	2.50	2.70	4.00
100.0	3.30	2.40	6.00	2.90	3.10	4.20
Particulars			LSD (p=0.05)			
A			0.027			
B			0.019			
AB			0.066			
CV			1.68			

Table 2. Effect of oil and its components on root length (cm)

Conc. (µg/mL)	Oil	Non-polar	Polar	Cyprene	Cyprene epoxide	Cyprene alcohol
0.5	3.76	1.50	3.53	1.73	2.70	3.06
1.0	3.90	1.70	3.56	1.90	2.86	3.20
2.0	4.10	1.83	3.80	2.00	2.90	3.40
2.5	4.48	1.90	3.93	2.10	3.00	3.60
5.0	4.70	2.00	3.86	2.30	3.06	3.70
10.0	5.00	2.16	4.16	2.70	3.20	3.70
20.0	5.23	2.40	4.23	2.86	3.30	3.80
25.0	5.26	2.50	4.46	3.00	3.43	4.00
50.0	5.30	2.66	4.70	3.10	3.73	4.10
75.0	5.60	3.00	4.93	3.30	3.90	4.30
100.0	5.69	3.16	5.10	3.56	4.00	4.70
Particulars			LSD (p=0.05)			
A			0.027			
B			0.020			
AB			0.068			
CV			1.21			

Likewise, fresh weight of the seedlings showed an increasing trend with the increasing concentration of the compounds as there is significant interaction between A and B. Statistically, all compounds showed significantly variant activity from each other but activity of Cyprene and non-polar fraction did not depict significant difference. Oil showed maximum effect in increasing the fresh weight of the seedlings at higher concentrations followed by cyprene alcohol **3** (**Table 3**).

A similar trend was observed in dry weight of seedling. Dry weight of the seedlings showed an increasing trend with the concentration of the compounds as there is significant interaction between A and B. All the compounds showed significantly variant activity from each other. Polar fraction

Table 3. Effect of oil and its components on fresh weight (mg)

Conc. (µg/mL)	Oil	Non-polar	Polar	Cyprene	Cyprene epoxide	Cyprene alcohol
0.5	35.31	19.27	29.24	21.34	31.21	33.04
1.0	36.30	20.25	29.22	21.31	32.20	34.05
2.0	38.28	20.23	30.20	22.29	34.17	36.07
2.5	39.24	21.20	32.18	24.26	35.06	37.08
5.0	41.22	23.19	33.16	25.24	36.21	39.09
10.0	42.20	24.17	34.14	26.21	37.20	40.11
20.0	44.18	27.16	36.13	26.20	39.08	41.13
25.0	45.17	29.15	39.12	28.19	40.14	43.14
50.0	47.16	31.13	42.11	30.17	44.20	44.17
75.0	49.14	33.12	43.10	31.16	45.25	45.20
100.0	51.13	36.11	45.10	32.15	46.33	47.21
Particulars			LSD (p=0.05)			
A			0.138×10^{-1}			
B			0.102×10^{-1}			
AB			0.338×10^{-1}			
CV			0.03			

Table 4. Effect of oil and its components on dry weight (mg)

Conc. (µg/mL)	Oil	Non-polar	Polar	Cyprene	Cyprene epoxide	Cyprene alcohol
0.5	10.01	4.15	15.54	6.00	11.45	13.31
1.0	10.40	5.50	16.69	7.25	12.64	14.30
2.0	11.11	7.96	17.33	9.16	13.72	16.30
2.5	12.58	8.54	19.75	11.85	15.68	17.24
5.0	13.02	9.38	20.25	12.62	16.65	18.28
10.0	14.25	11.58	21.92	13.23	17.98	20.03
20.0	16.30	13.18	24.83	14.21	19.39	22.58
25.0	18.18	14.96	26.77	15.04	20.42	24.95
50.0	20.00	17.28	29.58	18.98	23.25	28.65
75.0	22.75	20.33	31.34	20.26	25.00	30.00
100.0	24.54	21.69	34.21	21.00	27.01	31.54
Particulars			LSD (p=0.05)			
A			0.784×10^{-2}			
B			0.579×10^{-2}			
AB			0.019×10^{-1}			
CV			0.07			

showed maximum effect in increasing the dry weight of the seedlings at higher concentrations followed by cyprene alcohol **3** (**Table 4**).

The results of seedling vigour index showed that the polar fraction was found to be effective in improving the performance of the seeds in terms of germination followed by cyprene alcohol **3**, cyprene epoxide **2,** oil, cyprene **1** and its non-polar fractions (**Table 5**). But the oil and cyprene epoxide **2** showed no significant difference in their activities. The interaction between A and B was not found to be significant in seed vigour index. In an earlier study (Kaur *et al.* 2002), an investigation was done on the effect of *C. scariosus* oil on rooting, sprouting and accompanying biochemical changes in grapevine cuttings. An enhancement in number of primary roots, length of longest primary root, shoot length and also total dry weight of roots and shoots were observed over control (Kaur *et al.* 2002). Similarly,

Table 5. Effect of oil and its components on seedling vigour index

Conc. (µg/mL)	Oil	Non-polar	Polar	Cyprene	Cyprene epoxide	Cyprene alcohol
0.5	0.950	0.249	1.554	0.450	0.916	1.197
1.0	0.988	0.330	1.669	0.543	1.011	1.287
2.0	1.055	0.477	1.733	0.687	1.097	1.467
2.5	1.195	0.512	1.975	0.888	1.254	1.551
5.0	1.236	0.568	2.025	0.946	1.332	1.645
10.0	1.353	0.694	2.192	0.992	1.438	1.802
20.0	1.548	0.790	2.483	1.065	1.551	2.032
25.0	1.727	0.897	2.677	1.128	1.633	2.245
50.0	1.900	1.036	2.958	1.423	1.860	2.578
75.0	2.161	1.219	3.134	1.519	2.000	2.700
100.0	2.331	1.301	3.421	1.575	2.160	2.838
Particulars			LSD (p=0.05)			
A			0.029×10^{-5}			
B			0.154×10^{-5}			
AB			NS			
CV			0.003			

Table 6. Compounds with corresponding effective concentration order

Compound with effective concentration order				
Polar (Shoot length)	Oil (Root length)	Oil (Fresh Weight)	Polar (Dry Weight)	Polar (Seed Vigour index)
0.5^{h}	0.5^{d}	0.5^{g}	0.5^{f}	0.5^{f}
1.0^{hg}	1.0^{d}	1.0^{fg}	1.0^{f}	1.0^{ef}
2.0^{fg}	2.0^{cd}	2.0^{efg}	2.0^{f}	2.0^{ef}
2.5^{fe}	2.5^{bcd}	2.5^{ef}	2.5^{e}	2.5^{def}
5.0^{de}	5.0^{abcd}	5.0^{de}	5.0^{de}	5.0^{de}
10.0^{d}	10.0^{abc}	10.0^{de}	10.0^{d}	10.0^{cd}
20.0^{c}	20.0^{ab}	20.0^{cd}	20.0^{c}	20.0^{bc}
25.0^{c}	25.0^{ab}	25.0^{cc}	25.0^{c}	25.0^{cd}
50.0^{b}	50.0^{ab}	50.0^{bc}	50.0^{b}	50.0^{bc}
75.0^{a}	75.0^{a}	75.0^{ab}	75.0^{b}	75.0^{ab}
100.0^{a}	100.0^{a}	100.0^{a}	100.0^{f}	100.0^{a}

Tukey's Test (General linear model, Univariate, SPSS Software, 16.0):

*Compounds with similar alphabets are non-significant to each other and compounds with different alphabets are significant to each other.

effect of *C. scariosus* oil and its various fractions was studied on germination and seedling establishment in two cultivars of wheat. A promontory effect was reported on seed germination, number and length of roots, seedling dry weight and seedling vigour index (Sharma *et al.* 2016).

In the present study, the decreasing order of activity at different concentrations of *C. scariosus* oil, polar fraction, non-polar fraction, cyprene, cyprene epoxide and cyprene alcohol was as follows:

Polar fraction > *C. scariosus* oil > Cyprene alcohol > Cyprene epoxide > Cyprene > Non-polar fraction.

Table 7. Compounds with corresponding activity order

Parameter	Compound					
Shoot length	Oil[c]	Non-polar[e]	Polar[a]	Cyprene[e]	Cyprene epoxide[d]	Cyprene alcohol[b]
	2.39	1.56	3.78	1.76	2.27	2.98
Root length	Oil[a]	Non-polar[f]	Polar[b]	Cyprene[e]	Cyprene epoxide[d]	Cyprene alcohol[c]
	5.12	1.13	4.25	2.77	3.28	3.75
Fresh weight	Oil[a]	Non-polar[e]	Polar[d]	Cyprene[e]	Cyprene epoxide[c]	Cyprene alcohol[b]
	42.57	25.90	35.81	26.22	38.27	39.66
Dry weight	Oil[d]	Non-polar[f]	Polar[a]	Cyprene[e]	Cyprene epoxide[c]	Cyprene alcohol[b]
	15.74	12.23	23.47	13.60	18.47	21.56
Seed vigour index	Oil[c]	Non-polar[e]	Polar[a]	Cyprene[d]	Cyprene epoxide[c]	Cyprene alcohol[b]
	1.35	0.63	2.17	0.92	1.37	1.78

Tukey's Test (General linear model, Univariate, SPSS Software, 16.0):
*Compounds with similar alphabets are non-significant to each other and compounds with different alphabets are significant to each other.

The extract from *C. scariosus* plant has multiple pharmacological uses (Utreja *et al*. 2015). The present study and earlier reports also indicate plant growth regulator effects of *C. scariosus* oil.

From the germination studies on *C. annuum* L., it was concluded that the essential oil of *C. scariosus*, its polar and non-polar fraction, isolated compound-cyprene **1** and its derivatives-cyprene epoxide **2** and cyprene alcohol **3** have significant effect on the seedling growth parameters such as root length, shoot length, fresh weight and dry weight along with seed vigour index and act as promising plant growth regulator.

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Weed management in stone fruit nectarine orchard with inorganic mulches and herbicides

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ABSTRACT

The study has assessed the efficacy of different orchard floor management treatments on weed management in '*Snow Queen*' nectarine. The experiment was carried out in a randomized block design consisted of seven treatments having four replicates during the years 2016 and 2017. It has been found that the different orchard floor management treatments had a significant effect on weed density, weed fresh and dry weight, fruit quality and fruit yield of nectarine. All inorganic mulches (black polythene mulch, bicolour polythene mulch and nylon mulch mat) showed their superiority and provide complete elimination of weeds. Bicolour polythene mulch recorded maximum fruit size, weight, volume and TSS, whereas black polythene mulch recorded maximum fruit yield during both the years of study.

INTRODUCTION

Nectarine [*Prunus persica* (L.) Batsch var. *nucipersica*] is one of the emerging stone fruit crops of Himachal Pradesh. The lack of skin fuzz make nectarine skin appears more reddish than those of peaches, providing fruit's plum-like appearance. It can be cultivated all over the state except, dry and cold region of Lahul and Spiti and Kinnaur districts. However, mid hill zone, especially Rajgarh and Kullu valley areas are the main centers of nectarine cultivation because of highly congenial agro climatic conditions. In Himachal Pradesh, among stone fruits, peach/nectarine ranks next only to plum with an area and production of 5090 ha and 4097 MT, respectively (Anonymous 2017). However, no separate area and production data is available on the commercial level of nectarine.

Weed management is one of the various problems faced by the nectarine growers in the state. Weed interference has been reported to affect tree growth, fruit yield and fruit quality in nectarine by competing for light, water and nutrients (Negi 2015) and also provide potential breeding niche for various insect/pests and diseases. Weeds are also known to secrete root exudates in soil which adversely affect the plant growth and ultimately the yield. However, the magnitude of the effect on fruit yield and size depends on the weed species (Tworkoski and Glenn 2001).

Proper orchard floor management is one of the most important and effective tools in successful orcharding of nectarine. It controls weeds, conserves soil moisture, prevents soil erosion, maintains soil organic matter and structure, improves water infiltration and nutrient retention, and thereby enhances the fruit quality (Derr 2001). Among the different components of orchard floor management, hand weeding is the traditional method of controlling the weeds. But this method has always vexed the growers, being expensive and time consuming in addition to continuous damage to feeder root system of fruit trees. So, the recent trend has been shifted to chemical weed control without damaging the feeder roots. But being economic and effective method of weed control, it tends to damage main crop if not properly applied and also tend to decrease soil porosity by hardening the upper layers of soil. Also, the increased pressure to reduce herbicide applications and new interests in organic farming underline the importance of alternative approaches for orchard weed suppression (Goh *et al.* 2001). Hence, to meet the multiple objectives of efficient weed control and quality fruit production mulches should be used. Mulch may be organic or inorganic in nature, and their use depends upon their availability in a particular area. Mulches create congenial condition for plant growth by temperature moderation, moisture conservation, salinity reduction and weed control. They also exert decisive effects on earliness, yield and quality of crop (Bhardwaj 2013).

Keeping in view the need of weed management the present study was conducted to study the efficacy of different orchard floor management treatments on weed management in nectarine cv. Snow Queen.

MATERIALS AND METHODS

The present study was carried out on 10 years old plants of '*Snow Queen*' nectarine which were planted at a spacing of 5 × 5 m in the experimental orchard of Department of Fruit Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh (30° 51'N latitude and 76° 11'E longitude with 1250 m above mean sea level), during the years 2016 and 2017. The soil of the experimental site has a pH of 6.65, organic carbon of 1.51%, available nitrogen, phosphorus and potassium content of 312.6 kg/ha, 31.7 kg/ha and 320.6 kg/ha, respectively. The experiment was laid out in a randomized block design with seven treatments and four replications. Different orchard floor management treatments, *viz*. black polythene mulch (100 µ), bicolour polythene mulch (100 µ), nylon mulch mat (90 GSM), grass mulch (10-12 cm; local hay), chemical weed control (glyphosate at 3.25 l/ha), hand weeding and control (no orchard floor management treatment) were uniformly imposed in the first week of March. Spray of glyphosate and hand weeding was repeated at two- and one-month interval, respectively. Nutritional management practices were carried out as per standard package of practices of the university (Anonymous 2014).

The predominant weed flora of experimental orchard was identified and broadly grouped into monocot and dicot weeds. For recording weed density, permanent quadrants of 1.0 m^2 were randomly fixed at one location of each experimental plot (tree basin) before the emergence of weeds. Weed density was recorded at monthly interval of 30, 60, 90, 120 and 150 days after application of treatment of orchard management and results were expressed in number of weeds/m^2. For recording fresh and dry weight of weeds, the weeds were uprooted and washed to remove soil adhered to it, weight of fresh sample was recorded to get initial weight or fresh weight and dried it in hot air oven at 65 ± 2°C for 48 hours, then weighed again to get dried weight. The data on dry weight of weed was analysed statistically and were expressed in g/m^2. Weed control efficiency was expressed in percentage and calculated by using the following formula:

$$\frac{\text{Dry matter of weeds in control - Dry matter of weeds in treatment}}{\text{Dry matter of weeds in control}} \times 100$$

For fruit size ten randomly selected fruits from each experimental tree were recorded in terms of length and breadth with the help of digital Vernier Calliper (Mitutoyo, Japan). The average values of fruit length and breadth were expressed in millimetre (mm). For fruit weight, selected fruits taken for recording the fruit size data were weighed on electronic top pan balance and the average fruit weight was expressed in gram (g). Total soluble solids content was determined by Erma hand refractometer (0-32 ºBrix) by putting a few drops of fruit juice on its prism. The two years data was statistically analyzed with the standard procedure as suggested by Gomez and Gomez (1984). The level of significance for different variables was tested at 5% value of significance.

RESULTS AND DISCUSSION

Predominant weed species

The nectarine orchard was found to be infested with 8 monocot and 13 dicot weed species. The weed flora consisting mainly of *Cynodon dactylon*, *Cyperus rotundus*, *Chenopodium album* and *Euphorbia hirta etc*. have been presented along with their common names in **Table 1**. Among grasses and sedges, *Cynodon dactylon* and *Cyperus rotundus*, respectively were the most predominant species. Apart of these, *Chenopodium album* and *Oxalis latifolia* were other predominant species during the whole course of study. Similar type of weed flora was also observed by Negi (2015) in nectarine orchard.

Weed density

The orchard floor management treatments had a significant effect on weed density in nectarine during both the years of study (**Table 2**). Inorganic mulches, *viz*. black polythene mulch, bicolour polythene mulch and nylon mulch mat were equally effective in controlling weeds as there was no weed growth observed under these mulches. Maximum weed density after 30 days (298.00, 77.25 weeds/m^2), 60 days (477.50, 313.50 weeds/m^2), 90 days (526.50, 438.25 weeds/m^2), 120 days (453.25, 513.25 weeds/m^2) and 180 days (237.00, 260.25 weeds/m^2) was observed in T_7 (control) during 2016 and 2017, respectively.

No weed growth was observed under inorganic mulches might be due the preventive effect of these mulches on light penetration that acted as physical barrier affecting the growth of most of the annual and perennial weeds. It might create partially anaerobic conditions for the survival of weed species and thus finally resulting in no weed density (Iqbal *et al.* 2016). Maximum weed control under inorganic mulches was also observed by Shirgure *et al.* (2003) in Nagpur mandarin, Kaur and Kaundal (2009) in plum and Marak (2012) in plum.

Table 1. Predominant weed species in experimental nectarine orchard

Botanical name	Family	English name	Common name
Grasses			
Agropyron repens L.	Poaceae	Quack grass	-
Avena fatua L.	Poaceae	Wild oat	Jai
Cynodon dactylon L.	Poaceae	Bermuda grass	Doob
Digitaria sanguinalis L.	Poaceae	Crab grass	Takrighas
Echinochloa oryicola L.	Poaceae	Common barnyard grass	-
Setaria glauca (L.) Beauv.	Poaceae	Yellow fox tail	Banara
Sedge			
Cyperus rotundus L.	Cyperaceae	Nut sedge	Dila
Others			
Ageratum conyzoides L.	Asteraceae	Bill goat weed	Mahakana
Amaranthus viridis L.	Amaranthaceae	Pig weed	Chaoli
Bidens pilosa L.	Asteraceae	Beggers stick	Lumb
Cannabis sativa L.	Moraceae	Hemp	Bhang
Chenopodium album L.	Chenopodiaceae	Dowlamp bat	Bathu
Commelina benghalensis L.	Commelinaceae	Day flower	-
Convolvulus arvensis L.	Convolvulaceae	Wind weed	Hiran khur
Euphorbia hirta L.	Euphorbiaceae	Pod spurge	Bariduhi
Fumaria parviflora Lam.	Papaveraceae	Fineleaf fumitory	Pitpapra
Galinsoga parviflora Cav.	Borgariaceae	Gallant soldier	Piphe
Medicago sativa L.	Papilionaceae	Alfalfa	Maiha
Oxalis latifolia Kunth	Oxalidaceae	Garden pink-sorrel	Tipatiya
Oxalis corniculata L.	Oxalidaceae	Procumbent yellow-sorrel	Khatti meethi
Sonchus arvensis L.	Asteraceae	Field milk thistle	Daudhi

Table 2. Effect of orchard floor management treatments on weed density (no. of weeds/m^2) in nectarine

Treatment	30 Days		60 Days		90 Days		120 Days		150 Days	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Black polythene mulch	0	0	0	0	0	0	0	0	0	0
Bicolour polythene mulch	0	0	0	0	0	0	0	0	0	0
Nylon mulch mat	0	0	0	0	0	0	0	0	0	0
Grass mulch	36.5	16.7	128.5	74.5	135.2	95.0	42.5	76.5	107.7	54.0
Chemical weed control	20.5	18.0	174.2	149.2	28.5	26.0	174.5	154.0	47.5	45.7
Hand weeding	220.2	46.0	433.7	260.5	491.2	362.2	257.0	457.2	198.5	211.5
Control	298.0	77.2	477.5	313.5	526.5	438.2	453.2	513.2	237.0	260.2
LSD (p=0.05)	80.8	25.0	132.7	98.2	119.8	96.3	106.6	107.0	58.7	52.6

Fresh and dry weight of weeds

The orchard floor management treatments significantly influenced both fresh and dry weight of weeds in 2016 and 2017, respectively (**Table 3 and 4**). Among all treatments all inorganic mulches, *viz.* black polythene mulch, bicolour polythene mulch and nylon mulch mat recorded lowest value of both fresh and dry weed weight during the present course of study. Maximum value of after 30 days (227.38, 63.25 and 34.63, 15.50 g/m^2 respectively), 60 days (395.75, 452.63 and 83.75, 99.13 g/m^2 respectively), 90 days (624.63, 611.00 and 113.13, 131.75 g/m^2 respectively), 120 days (1075.75, 1118.88 and 225.88, 230.88 g/m^2, respectively) and 180 days (501.25, 508.63 and 123.00, 138.25 g/m^2 respectively) was observed in control during 2016 and 2017, respectively.

Inorganic mulches maintained their superiority in terms of low fresh and dry weed weight as they suppressed the weed growth by acting a surface barrier. Low weed density (or no weed growth) under these mulches (**Table 2**) is responsible for lower values of fresh and dry weed weight as compared to all other treatments. The results of present study are in consonance with the findings of Iqbal *et al.* (2016) in '*NA-7*' aonla, Negi (2015) in '*Snow Queen*' nectarine, Thakur *et al.* (2012) in '*Earli Grande*' peach and Marak (2012) in pecan.

Weed control efficiency

Among all orchard floor management treatments, inorganic mulches, *viz.* black polythene mulch, bicolour polythene mulch and nylon mulch mat showed maximum weed control efficiency of 100% and minimum of 0% as compared to all other treatments during the present course of study **Table 5** . High weed control efficiency under inorganic mulches might be due to their shading property which will suppress the weed growth below these mulches. Maximum weed control efficiency under inorganic (plastic) mulches was also recorded by Thakur *et al.*

(2012) in '*Earli Grande*' peach. The results were also in accordance with the findings of Kaundal *et al.* (1995), Buban *et al.* (1997) and Shylla *et al.* (2003) in different fruit crops.

Fruit quality

The orchard floor management treatments had a significant effect on fruit quality in nectarine (**Table 6**). The maximum fruit size (length- 52.8, 57.3 mm, breadth- 51.2, 55.0 mm), fruit weight (77.9, 89.4 mm) and total soluble content (12.8, 12.9 ºB) were recorded under bicolour polythene mulch during both the years of study which was closely followed by black polythene mulch. Maximum fruit size, fruit weight and TSS of nectarine fruits under bicolour polythene mulch were attributed to reflective property of bicolour mulch to reflect back the light in tree canopy which resulted increase in photosynthesis and ultimately increase in fruit size, weight and TSS. The present study confirmed the findings of Shiukhy *et al.* (2015), Sharma *et al.* (2013) and Posada *et al.* (2011) who also observed increased fruit size and fruit weight in strawberry by using bicolour mulches. These results were also supported by the findings of Sharma *et al.* (2017) who recorded increased fruit quality of '*Snow Queen*' nectarine under bicolour polythene mulch.

Fruit yield

Black polythene mulch recorded the maximum fruit yield (16.98, 21.85 t/ha) during 2016 and 2017, respectively. Minimum fruit yield (9.00 and 15.32 t/ha respectively) was recorded under control (**Table 6**). The highest yield under black polythene mulch might be due to good hydrothermal regimes and efficient weed control during the fruit development period as compared to all other treatments which contributed for increased fruit set and lesser fruit drop and ultimately results to highest yield. The present findings for fruit yield were similar to the findings of several other workers who have also reported that black polythene mulches greatly influenced the yield (Sharma and Sharma 2018, Sharma and Kathiravan 2009 and Szewczuk and Gudarowska 2006) in different fruit crops.

Table 3. Effect of orchard floor management treatments on fresh weed weight (g/m^2) in nectarine

Treatment	30 Days		60 Days		90 Days		120 Days		150 Days	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Black polythene mulch	0	0	0	0	0	0	0	0	0	0
Bicolour polythene mulch	0	0	0	0	0	0	0	0	0	0
Nylon mulch mat	0	0	0	0	0	0	0	0	0	0
Grass mulch	60.75	18.25	72.00	76.00	138.88	94.50	123.13	105.25	99.00	47.63
Chemical weed control	17.00	31.75	171.88	153.87	14.00	18.25	150.50	208.75	25.75	27.75
Hand weeding	178.25	62.63	372.13	396.38	616.75	541.63	505.38	707.25	193.00	268.00
Control	227.38	63.25	395.75	452.63	624.63	611.00	1075.75	1118.88	501.25	508.63
LSD (p=0.05)	70.44	22.72	87.45	107.25	175.07	126.59	377.51	272.71	250.81	192.44

Table 4. Effect of orchard floor management treatments on dry weed weight (g/m^2) in nectarine

Treatment	30 Days		60 Days		90 Days		120 Days		150 Days	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Black polythene mulch	0	0	0	0	0	0	0	0	0	0
Bicolour polythene mulch	0	0	0	0	0	0	0	0	0	0
Nylon mulch mat	0	0	0	0	0	0	0	0	0	0
Grass mulch	6.00	1.25	7.88	10.75	29.25	11.00	21.63	14.88	15.63	11.50
Chemical weed control	2.38	6.50	33.50	23.38	2.50	3.50	33.50	34.36	6.50	5.13
Hand weeding	27.50	15.25	70.75	77.63	109.50	116.63	104.00	161.13	50.38	87.63
Control	34.63	15.50	83.75	99.13	113.13	131.75	225.88	230.88	123.00	138.25
LSD (p=0.05)	7.62	2.47	23.38	25.27	28.92	34.39	75.19	62.76	66.29	62.34

Table 5. Effect of orchard floor management treatments on weed control efficiency (%) in nectarine

Treatment	30 Days		60 Days		90 Days		120 Days		150 Days	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Black polythene mulch	100	100	100	100	100	100	100	100	100	100
Bicolour polythene mulch	100	100	100	100	100	100	100	100	100	100
Nylon mulch mat	100	100	100	100	100	100	100	100	100	100
Grass mulch	82.67	91.94	90.59	89.15	74.14	91.65	90.42	93.56	87.29	91.68
Chemical weed control	93.13	58.06	60	76.41	97.79	97.34	85.17	85.11	94.71	96.29
Hand weeding	20.58	1.61	15.52	21.69	3.21	11.47	53.96	30.21	59.04	36.61
Control	0	0	0	0	0	0	0	0	0	0

Table 6. Effect of orchard floor management treatments on fruit quality and fruit yield quality in nectarine

Treatment	Fruit length (mm)		Fruit breadth (mm)		Fruit weight (g)		TSS (ºB)		Fruit yield (t/ha)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Black polythene mulch	52.03	56.71	50.59	54.32	77.22	88.78	12.62	12.80	16.98	21.85
Bicolour polythene mulch	52.85	57.27	51.21	55.04	77.86	89.41	12.78	12.92	16.05	21.37
Nylon mulch mat	51.15	55.99	50.20	53.79	74.10	87.62	12.49	12.69	14.98	20.09
Grass mulch	50.69	55.03	49.55	52.94	72.81	86.69	12.34	12.51	13.46	18.78
Chemical weed control	49.75	54.61	48.32	52.68	70.69	81.99	12.15	12.31	11.37	16.67
Hand weeding	48.56	53.98	47.35	51.53	69.58	81.11	12.08	12.20	10.33	16.38
Control	47.07	51.16	45.91	49.28	66.93	77.38	11.48	11.71	9.00	15.32
LSD (p=0.05)	1.20	1.32	0.95	0.97	1.91	1.48	0.64	0.56	1.02	1.15

It was concluded that efficacy of inorganic mulches was superior to all other treatments in terms of weed density, fresh and dry weed weight and weed control. Black polythene mulch was the best treatment for fruit yield while fruits with best fruit quality were recorded under bicolour polythene mulch. Keeping in view of weed control efficacy, fruit quality and fruit yield, use of black and bicolour polythene mulches is the best orchard floor management treatment in nectarine orchard.

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Weed management effects on cotton growth and yield

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ABSTRACT

Field experiments were conducted during winter seasons of 2008-09 and 2009-10 at Eastern Block Farm, Tamil Nadu Agricultural University, Coimbatore to study the efficiency of new formulation of pre-emergence herbicide pendimethalin 38.7% on growth and development of cotton with better weed management in a cost effective manner, under irrigated condition. Pendimethalin 38.7% was tried in four different doses, *viz.* 1.5, 2.0, 2.5 and 4.0 kg/ha and it was compared with pendimethalin 30% 1.0 kg/ha, early post-emergence herbicide trifloxysulfuron, power weeders and hand weeding. The pre-emergence application of pendimethalin (38.7%) at 2.0 kg/ha at 3 days after seeding (DAS) followed by hand weeding and earthing at 45 DAS did not show any phytotoxic effect on cotton and recorded lower weed density and biomass with increased the seed cotton yield by about 41.5% over unweeded control and higher net returns.

INTRODUCTION

Cotton the "*white gold* or the *king of fibres*" is one of the most important commercial crops in India. In India, cotton cultivation provides livelihood for over 4 million farming families. It produces only 3.77 million bales of lint every year with a productivity of 524 kg/ha (ICAR, Annual report, 2017-18. The key role that cotton plays in our country can be gauged that nearly 15 million farmers spread out in more than 10 states are dependent on cotton cultivation (Prasad and Prasad 2009).

Weed infestation in cotton has been reported to offer severe competition and causing yield reduction to an extent of 40 to 85% (Sreenivas 2000, Gnanavel and Babu 2008). Weeds which emerge with cotton plants offer a severe competition and bring about considerable reduction in seed cotton yield. Reduction in seed cotton yield under irrigated conditions is primarily due to nutrient depletion caused by weeds and may vary over from 10-90 per cent (Singh 1988). Cotton with minimal weed competition during the initial phase *ie*., three to five weeks would yield better (Mohamed Ali and Bhanumurthy 1985). Thus, there is need for selection of new molecules of pre-emergence to control weeds during initial crop period.

MATERIALS AND METHODS

Field experiments were laid out in Field No. 73 and 36C during winter seasons of 2008-09 and 2009-10, respectively in Eastern Block farm of Tamil Nadu Agricultural University, Coimbatore. The farm is situated at 11° North latitude and 77° East longitude at an altitude of 426.72 m above Mean Sea Level. The mean annual rainfall of Coimbatore is 670.6 mm distributed in 47 rainy days. The mean maximum and minimum temperatures are 30.6 and 20.9°C, respectively. During winter 2008-09, maximum temperature during the cropping period ranged from 27°C to 34.7°C with a mean of 30.9°C. The minimum temperature ranged from 14^{0}C to 24.5°C with a mean of 20.6°C. The relative humidity ranged from 71 to 98% with a mean of 87.9%. A total rainfall of 321.1 mm was received in 18 rainy days during the cropping period. During winter 2009-10, maximum temperature during the cropping period ranged from 27.2°C to 33.2°C with a mean of 30.6°C. The minimum temperature ranged from 14.5°C to 24.7°C with a mean of 22.26°C. The relative humidity ranged from 70 to 97% with a mean of 87%. A total rainfall of 516.8 mm was received in 27 rainy days during the cropping period The soils of the experimental sites were sandy clay loam in texture with low in available nitrogen, medium in available phosphorus and high in available potassium. The field was irrigated once in a week and depend on the climatic condition.

The experiment was laid out in a randomised blocks design with three replications. The treatments were allotted at random in each replication. The weed management practices evaluated in the present study consisted of chemical weed control (application of pre-emergence, Pre-emergence application on 3rd day after sowing and early post-emergence herbicides, early post-emergence was applied 10 days after sowing), cultural practices (mulching with straw) and manual weeding (hand weeding once and twice) and weed free situation (hand weeding 10 times) and unweeded control. The weed management practices tested include: pendimethalin PE at 1.5, 2.0, 2.5 and 4.0 kg/ha followed by (*fb*) hand weeding (HW), pendimethalin PE at 1.0 kg/ha *fb* HW, trifloxysulfuron at 10 g/ha early post-emergence (EPoE) *fb* HW, pendimethalin PE at 1.0 kg/ha *fb* PWW, pendimethalin at 1.0 kg/ha *fb* CRM + HW, PWW on 25 and 45 DAS, hand weeding twice at 25 and 45 DAS, weed free and unweeded checks were included. The soils of the experimental sites were sandy clay loam in texture with low in available nitrogen, medium in available phosphorus and high in available potassium. Cotton (*Gossypium hirsutum* L.) variety MCU 13 was raised during winter season of 2008-09 and Thulsi Bt during 2009-10.

RESULTS AND DISCUSSION

Effect on weed

Pendimethalin (38.7%) at 2.0 to 4.0 kg/ha *fb* one hand weeding at 45 DAS resulted in effective control of grasses, broad-leaved weeds and to some extent sedges due to its broad spectrum action. It enters grasses through the coleoptile and shoot of the seedling below the ground. (Vencill 2002) Thus, grasses were effectively controlled with this herbicide. The left over weeds were controlled by manual weeding at 45 DAS. Application of pendimethalin at higher dose of 1.5 kg/ha recorded weed density when compared to lower doses as was reported by Chander *et al.* 1997.

Weed biomass depicted a similar response as the weed density in various treatments. The reduced weed density under pendimethalin (38.7%) at 2.0 to 4.0 kg/ha had resulted in reduced weed biomass at all the stages of crop growth. This might be attributed to rapid depletion of carbohydrate reserve of the weeds through rapid respiration (Prakash *et al.* 1999). The biomass of grasses, sedges and broad-leaved weeds were reduced due to different weed management treatments. Panwar *et al.* (2001) also reported that application of pendimethalin at 1.0 kg/ ha has reduced weed density and biomass significantly over the unchecked weed growth.

Cotton growth attributes

Pendimethalin 2.0 kg/ha *fb* hand weeding recorded higher plant height and was closely followed by pendimethalin 2.5 kg/ha *fb* hand weeding. This might be due to better weed control in the above treatments which resulted in efficient utilization of light, water and nutrients than other treatments. Unchecked weed growth in unweeded control reduced the plant height. This was attributed to suppressing effect of weeds on crop plants (Chander *et al.* 1997). Heavy weed competition reduced the nutrient uptake by crop and reduced the growth of crop as evidenced from the lowest plant height in unweeded control (Balasubramanian 1985).

Leaf area index, an important growth parameter which decides the photosynthetic activity and the dry matter production of crop. Among different weed management methods, the cotton with pendimethalin 2.0 kg/ha *fb* hand weeding treatment had higher leaf area index followed by pendimethalin 2.5 kg/ ha *fb* hand weeding due to increased WCE and reduced weed density. The next best treatment was pendimethalin 1.0 kg/ ha *fb* hand weeding at 45 DAS.

Table 1. Effect of treatments on total weed density and biomass at 25 DAS

Treatment	Weed density (no./m^2)		Weed biomass (kg/ha)	
	Winter 2008-09	Winter 2009-10	Winter 2008-09	Winter 2009-10
Pendimethalin 1.5 kg/ha *fb* hand weeding (HW)	10.14(34.7)	9.81(33.1)	10.54(111.1)	8.16(66.7)
Pendimethalin 2.0 kg/ha *fb* HW	8.27(23.2)	7.91(21.8)	8.34(69.5)	5.71(32.6)
Pendimethalin 2.5 kg/ha *fb* HW	8.26(23.0)	7.79(21.3)	8.31(69.0)	5.45(29.7)
Pendiimethalin 4.0 kg/ha *fb* HW	7.98(21.5)	7.65(20.4)	8.25(68.1)	5.25(27.5)
Pendiimethalin 1.0 kg/ha *fb* HW	10.44(36.8)	10.04(34.5)	10.92(119.3)	8.40(70.6)
Trifloxysulfuron 10 g/ha EPoE *fb* HW	11.83(58.0)	11.36(51.6)	10.91(118.9)	11.76(138.2)
Pendiimethalin 1 kg/ha *fb* PWW	10.66(38.6)	10.13(35.3)	11.05(122.2)	8.56(73.2)
Pendiimethalin 1 kg/ha *fb* CRM *fb* HW	10.75(39.3)	10.17(35.8)	10.88(118.4)	8.55(73.0)
PWW at 25 and 45 days after sowing	17.25(102.4)	17.03(100.6)	21.60(466.6)	20.20(408.0)
HW at 25 and 45 days after sowing	17.53(106.7)	16.52(94.7)	20.98(440.3)	19.93(397.1)
Weed free check	6.52(14.5)	6.48(14.6)	3.02(9.1)	2.75(7.6)
Unweeded control	18.19(114.5)	17.68(108.6)	22.38(500.8)	20.51(420.5)
LSD (p=0.05)	0.73	0.70	1.46	1.18

PE = Pre-emergence application; EPoE =Early post-emergence PWW= Power weeder weeding CRM= Crop residue mulch

This might be probably due to better control of grasses and broad-leaved weeds. Unweeded control recorded the least LAI of cotton after 30 DAS due to severe weed competition for light and nutrient resulting in the production of small leaves and thus leading to the reduction in leaf area (Muruganandam 1984).

Lesser weed crop competition of the crop and more conservation of the soil moisture, nutrient and space resulted in better vegetative growth and dry matter production (DMP) of crop under effective weed control treatments. Pendimethalin 2.0 and 2.5 kg/ha *fb* hand weeding showed higher cotton biomass over other herbicide treatments. This might be due to effective control of weeds at critical stages and suppression of late emerged weeds by vigorous growth of cotton crop. Among the weed management treatments, pendimethalin 4.0 kg/ha *fb* hand weeding produced lesser biomass. The reason might be due to the initial phytotoxicity of the herbicide to the crop resulted in lesser biomass. Unweeded control registered lowest biomass due to the competition by excessive weed growth. Similar finding of decrease in cotton biomass by increased weed density under ineffective weed management practices was reported by Bhoi *et al.* (2007).

Application of pendimethalin 2.5 kg/ha *fb* hand weeding recorded higher NPK uptake by cotton at 30 DAS. In the remaining stages, pendimethalin 2.0 kg/ha *fb* hand weeding enhanced the uptake of nutrients. This might be due to better control of broad-leaved weeds and sedges during early stages of crop growth, which favoured the crop to utilize the available nutrients. Due to higher weeds biomass in this treatment the crop uptake of NPK was lesser than other treatments. Similar finding of decrease in dry matter production of cotton by increased weed density with ineffective weed control situation was reported by Singh (1983).

Yield attributes

Application of pendimethalin at 2.0 kg/ha + hand weeding recorded more number of bolls/plant and was closely followed by pendimethalin at 2.5 kg/ha + hand weeding. This was in accordance with the findings of Nehra *et al.* (1988). Unweeded control treatment recorded lesser boll weight due to season long infestation of weeds.

Table 2. Effect of weed management treatments on cotton plant height, leaf area index and dry matter production

Treatment	Plant height (cm) (60 DAS)		Leaf area index (60 DAS)		Biomass (kg/ha) (60 DAS)	
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
Pendimethalin 1.5 kg/ha *fb* hand weeding (HW)	36.63	55.43	0.82	1.06	1776	1881
Pendimethalin 2.0 kg/ha *fb* HW	44.23	63.06	0.89	1.13	1982	2116
Pendimethalin 2.5 kg/ha *fb* HW	41.00	57.40	0.87	1.11	1963	2059
Pendiimethalin 4.0 kg/ha *fb* HW	28.65	44.00	0.66	0.90	1691	1522
Pendiimethalin 1.0 kg/ha *fb* HW	36.49	54.74	0.80	1.04	1763	1866
Trifloxysulfuron 10 g/ha EPoE *fb* HW	34.78	52.49	0.82	1.06	1722	1768
Pendiimethalin 1 kg/ha *fb* PWW	35.50	56.55	0.78	1.02	1789	1857
Pendiimethalin 1 kg/ha *fb* CRM *fb* HW	34.63	55.40	0.80	1.04	1756	1827
PWW at 25 and 45 days after sowing	28.15	48.95	0.73	0.97	1600	1627
HW at 25 and 45 days after sowing	43.03	58.89	0.90	1.14	1966	2089
Weed free check	46.63	67.30	1.12	1.26	2163	2358
Unweeded control	23.20	44.43	0.60	0.84	1454	1506
LSD (p=0.05)	7.55	5.28	0.07	0.064	182	250

Table 3. Effect of weed management treatments on cotton N, P and K uptake

Treatment	Nitrogen uptake (kg/ha)		Phosphorus uptake (kg/ha)		Potassium uptake (kg/ha)	
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
Pendimethalin 1.5 kg/ha *fb* hand weeding (HW)	13.57	14.38	3.71	3.93	20.05	21.24
Pendimethalin 2.0 kg/ha *fb* HW	15.65	16.71	4.36	4.65	23.54	25.13
Pendimethalin 2.5 kg/ha *fb* HW	14.69	15.41	4.15	4.36	22.45	23.55
Pendiimethalin 4.0 kg/ha *fb* HW	12.50	11.05	3.16	2.79	17.07	15.09
Pendiimethalin 1.0 kg/ha *fb* HW	14.46	15.08	3.66	3.82	19.78	20.63
Trifloxysulfuron 10 g/ha EPoE *fb* HW	12.75	13.32	3.37	3.52	18.20	19.03
Pendiimethalin 1 kg/ha *fb* PWW	13.05	13.75	3.39	3.57	18.33	19.30
Pendiimethalin 1 kg/ha *fb* CRM *fb* HW	14.76	15.35	3.37	3.51	18.23	18.96
PWW at 25 and 45 days after sowing	13.12	13.33	3.07	3.12	16.61	16.88
HW at 25 and 45 days after sowing	12.70	13.49	4.16	4.42	22.49	23.90
Weed free check	16.43	17.92	4.82	5.26	26.07	28.42
Unweeded control	9.96	10.32	2.40	2.48	12.96	13.42
LSD (p=0.05)	2.91	3.05	0.79	0.83	4.29	4.51

PE = Pre emergence application; EPoE =Early post-emergence PWW= Power weeder weeding CRM= Crop residue mulch

Table 4. Effect of weed management treatments on yield attributes and yield of cotton

Treatment	Winter 2008-09			Winter 2009-10		
	No. of bolls/plant	Boll weight (g/boll)	Seed cotton yield (t/ha)	No. of bolls/plant	Boll weight (g/boll)	Seed cotton yield (t/ha)
Pendimethalin 1.5 kg/ha *fb* hand weeding (HW)	18.64	3.80	1.38	33.14	4.84	2.60
Pendimethalin 2.0 kg/ha *fb* HW	22.55	4.00	1.67	37.05	5.07	3.27
Pendimethalin 2.5 kg/ha *fb* HW	20.67	3.97	1.52	35.17	5.04	2.94
Pendiimethalin 4.0 kg/ha *fb* HW	14.40	3.20	1.32	28.90	4.23	2.47
Pendiimethalin 1.0 kg/ha *fb* HW	18.40	3.90	1.49	32.90	4.67	2.83
Trifloxysulfuron 10 g/ha EPoE *fb* HW	18.23	3.75	1.44	32.73	4.82	2.79
Pendiimethalin 1 kg/ha *fb* PWW	17.45	3.78	1.34	31.95	4.85	2.55
Pendiimethalin 1 kg/ha *fb* CRM *fb* HW	18.57	3.60	1.33	33.07	4.67	2.58
PWW at 25 and 45 days after sowing	16.60	3.79	1.30	31.10	4.88	2.33
HW at 25 and 45 days after sowing	22.50	3.50	1.66	37.00	4.92	3.24
Weed free check	26.46	4.10	1.82	40.96	5.17	3.50
Unweeded control	10.00	2.90	0.98	24.50	3.97	1.62
LSD (p=0.05)	3.85	0.12	0.14	1.78	0.18	0.22

PE = Pre-emergence application; EPoE =Early post-emergence PWW= Power weeder weeding CRM= Crop residue mulch

Seed cotton yield

Due to heavy infestation of weeds under unweeded check, there was 32 to 58% reduction in seed cotton yield. Hand weeding twice recorded lower seed cotton yield during winter season due to poor control of grasses and broad-leaved weeds. During both 2008-09 and 2009-10, the maximum seed cotton yield of (1.67 t/ha and 3.27 t/ha, respectively) was registered with the application of pendimethalin 2.0 kg/ha + HW and the yield under this treatment was comparable with hand weeding twice (1.66 t/ha and 3.24 t/ha, respectively). The yield increase under pendimethalin 2.0 kg/ha + HW was 9.6, 10.5 and 13.5% in 2008-09 and 10.1, 13.3 and 14.6% in 2009-10, over pendimethalin 2.5 kg/ha + HW, pendimethalin 1.0 kg/ha + HW and trifloxy-sulfuron 10 g/ha + HW, respectively during 2008-09. Pendimethalin at 2.0 kg/ha + hand weeding recorded 41.5 and 50% higher seed cotton yield of over unweeded control during 2008-09 and 2009-10, respectively. Application of pendimethalin at 1.0 kg/ha in combination with inter culturing plus hand weeding gave 199.4 per cent increase in seed cotton yield over untreated check was reported by Ali *et al*. (2005). Gnanavel and Babu (2008) also reported maximum seed cotton yield with pendimethalin and fluchloralin combination coupled with hand weeding as compared with control. Due to heavy infestation of weeds under unweeded check, there was 32 to 58% reduction in seed cotton yield.

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Biology of weed flora, weed dynamics and weed management in different fodder crops

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ABSTRACT

Appraisal has been made at the fodder farm of ICAR-IVRI, Izatnagar campus by following standard procedure adopted by AICRP on Weed Management (ICAR) during 2015 and 2016. Results revealed that *Trianthema portulacastrum* and *Trianthema monogyna* were widely distributed in the fodder farm during summer and rainy seasons. It produced flower continuously up to second fortnight of November with 224 to 504 seeds/plant and multiplied both by seeds (More than 80% germination of current seeds) and fragmented plant parts. Another broad-leaved weed *Celosia argentea* preferred the growing condition of fodder sorghum and it produced 1,716 to 3,496 seeds/plant. The broadleaved weed *Coccinia grandis* was associated with fodder maize and sorghum, and produced 2,934 to 4,428 seeds/plant. Numerous seed production capacity of these weeds supported its high profile emergence. Among the other weeds the grasses were widely distributed, whereas the sedges were appeared in patches. Three major broad-leaved weeds *Coronopus didymus, Rumex dentatus* and *Cichorium intybus* appeared during 1st, 2nd, 3rd and 4th cutting of berseem during winter season, respectively. The weeds *Trianthema portulacastrum, Trianthema monogyna, Coccina grandis, Rumex dentatus* and *Cleome viscosa* had shown the character of endozoochory dissemination. Uniform distribution of rainfall during 2015 caused rapid infestation of broad-leaved weeds (*Trianthema* sp., *Coccinia grandis, Celosia argentea*) whereas huge down pour within short period during monsoon season of 2016 caused submergence which, in turn, reduced infestation of broad-leaved weeds and side by side increased invasion of grasses. Mixed cropping of fodder maize (Variety '*African Tall*') and fodder cowpea (Variety '*Bundel Lobia* 2') controlled *Trianthema* sp. and maximum green fodder yield was obtained at 55 days after sowing beyond that cowpea showed competitive effect on maize. Turning the land from fodder sorghum to cowpea minimised distribution and seed production capacity of *Celosia argentea*. Mixed cropping of berseem (Variety '*Wardan*') + gobhi sarson (*Brassica napus* var. *napus*) and berseem (Variety '*Wardan*') + rye grass (Variety '*Makkhan Grass*') reduced infestation of *Coronopus didymus*. Growing of dual purpose (grain-cum-green fodder) wheat variety '*VL Gehun* 829' reduced infestation of resistant biotype of *Phalaris minor*.

INTRODUCTION

Like grain crops weeds are also considered as a major constraint in fodder crops. Weeds possess several characters and that attribute advantages of weeds on fodder crops. Weeds with high dry matter accumulation capacity offer strong competition to the fodder crops for growth factors since emergence of seedlings of fodder crops. Maximum crop weed competition occurs up to 4-5 weeks in most of the seasonal forage. Weed control at early stages of fodder crops is an important operation for better establishment. The losses caused by the weeds vary with the season, crop and variety. The loss in fodder yield due to weed competition has been reported to the extent of 11.7% in lucerne and 8.3% in oat. In crop like sorghum, magnitude of yield loss was as high as 54%, while uptake of nitrogen, phosphorous and potassium by weeds was to the extent of 48.8, 22.0 and 55.0 kg/ha, respectively. In berseem, the extent of yield reduction due to weed flora has been estimated to the extent of 23 to 28% in case of green fodder yield and 38 to 44% in case of seed yield (Wasnik *et al.* 2017). Therefore, the infestation of weed in forages needs to be checked starting from land preparation (Sunil *et al.* 2012). Yaduraju (2012) estimated a total economic loss in arable crops equivalent to approximately USD 13 billion per annum. In addition to direct effect on yield, weeds result in a considerable reduction in the efficiency of input used and quality (Yaduraju *et al.* 2018). Admixture of weeds with green fodder during harvest like *Coronopus didymus* with berseem, *Coccinia grandis* with fodder maize and sorghum, *Celosia argentea* with fodder sorghum, *Trianthema* with fodder maize and sorghum, reduces palatability of green fodder and thus affects milk production of milch animals. Because of their ability to persist and spread through the multiple reproduction and dispersal of dormant seeds/vegetative propagules, and for this reason weeds are virtually impossible to eliminate from any given field (Singh 2014 and Sharma 2014). Therefore, cultural methods, which includes mixed cropping, stale seedbed technique, turning the land to other crops, using smother crop etc. provide competitive advantage to crop against weeds by reducing weed establishment (Singh 2014).

Since, very limited information is available about weed flora and weed dynamics in fodder crops, and weeds are the major constraints in cultivation of fodder crops, generation of data on weed flora, weed dynamics and weed management in fodder crops is essential. Considering the above fact, the research activities have been planned and executed with the objective to generate information on weed flora, weed dynamics and weed management in different fodder crops.

MATERIALS AND METHODS

The weed flora have been surveyed by following standard procedure for weed survey as followed by All India Coordinated Research Project on Weed Management (ICAR), by plotting one meter square quadrats in randomized manner. The weed flora have been surveyed at different stages of fodder crops from the same field. Absolute and relative values of density, frequency and basal area and ultimately importance value index for each of the species in each situation and time of weed record have been determined to screen out the dominance spectrum of the species. The weed biology *i.e.* time of flowering, seed production, mode of propagation has been determined based on field observation. The calculations have been used to determine absolute density, relative density, absolute frequency, relative frequency, important value and summed dominance ration of the weeds appeared in different crops (Raju 1997) and the data have been expressed in the form of absolute density and absolute frequency in order to highlight population and distribution of the weeds appearing in different fodder crops grown in different seasons. Pot experiments have been conducted to generate information about regeneration capacity of fragmented plant parts of *Trianthema* sp. at its different ages.

Laboratory experiments were conducted with the help of Petridish and blotting paper to generate information about germination of current seeds (%) of the weeds. Experiment on mixed cropping of maize + cowpea has been conducted with 50% seed rate of each crop (22 kg/ha of variety *'African Tall'* of fodder maize and 15 kg/ha of fodder cowpea variety '*Bundel Lobia* 2') and fertilizer dose of NPK (kg/ha) ratio 60:70:32 with the help of chemical fertilizer having NPK ratio of 12:32:16 as basal application and 34 kg of N/ha was applied as urea at 35 days after sowing. Mixed cropping of berseem (Variety '*Wardan*') + gobhi sarson (*Brassica napus* var. *napus)* was grown with the seed rate of 25 kg berseem/ha and 600 g gobhi sarson/ha and fertilizer dose of NPK (kg/ha) ratio of 26:70:32 with the help of chemical fertilizer having NPK ratio of 12:32:16 was applied as basal in puddled condition. Mixed cropping of berseem (Variety '*Wardan*') + rye grass (Variety '*Makkhan Grass*') was grown with 50% seed rate of both the crops (Berseem 12.5 kg/ha and rye grass/ makkhan grass 4 kg/ha) in un-puddled condition and fertilizer dose of NPK (kg/ha) ratio 26:70:32 with the application of chemical fertilizer having NPK ratio of 12:32:16 as basal application was adopted. 20 kg N/ha was applied in form of urea after 1st and 2nd cutting. Irrigation was given at 15 days interval and immediately after cutting both in berseem + gobhi sarson and berseem + rye grass. The dual purpose wheat (Grain-cum-green fodder) was grown with the seed rate of 120 kg/ha of each variety '*VL Gehun* 829' and '*VL Gehun* 616'. The fertilizer dose of NPK (kg/ha) ratio of 120:60:40 was applied in form of urea, SSP and MOP. The nitrogen was applied in 4 equal split doses as basal, 35 days after sowing (DAS), immediately after cutting (57 DAS) for green fodder and 30 days after cutting. Six irrigations were given at 20 DAS, 35 DAS, immediately after cutting for green fodder, 30 days after cutting, booting and grain filling stages.

RESULTS AND DISCUSSION

Weed biology

Among the weeds appeared during pre-*Kharif* and *Kharif* seasons, *T. portulacastrum* and *T.*

monogyna were widely distributed in fodder farm and this was mainly because of its strong character on seed production and multiplication both by seed and vegetative means. Each *Trianthema* flower produced 224 to 504 seeds/plant. two to three per cent of the total current seeds germinated within 6 days after imbibition, majority of the seeds germinated within 17 to 20 days after imbibition and remaining seeds germinated afterwards. This finding was corroborated with the finding of Professor Jayashankar Telangana Agricultural Univerity (PJTSAU) centre of All India Coordinated Research Project (AICRP) on Weed Management (Anonymous 2017). 10 days old plant of *Trianthema* spp. was controlled through stale seedbed technique and beyond that stage fragmented plant parts put forth the new growth. Emergence and growth of the weed was highly susceptible to high soil moisture and submerged condition. Water stagnation for the period of 1 to 2 days inhibited emergence and also restricted growth of *Trianthema* and it was also subjected to biological stresses, which restricted the growth of the weed. High feeding activity of insect (larva) was observed in high humid condition during monsoon season. Natural infection of fungus as leaf spot was also observed and the weed perished due to fungal infection during first or second fortnight of November.

The mature plant of *Celosia argentea* produced 1,716 to 3,496 seeds/plant when it was associated with fodder sorghum. One mature *Coccinia grandis* plant produced 2,934 to 4,428 seeds/plant and *Cleome viscosa* produced 672 to 1755 seeds/plant. Seeds of *Trianthema* spp., *Coccinia grandis, Rumex dentatus* and *Cleome viscosa* have shown the character of endozoochory mechanism of dispersion and passed through the cattle rumen successfully. The seeds became viable into fresh cattle dung. Application of undecomposed manure/FYM and use of cattle shed water for irrigation led to disseminate these weeds into the fields. Three major broad-leaved weeds *Coronopus didymus, Rumex dentatus, Cichorium intybus* were appeared during 1st, 2nd, 3rd and 4th cutting of berseem, respectively, during winter season.

Weed dynamics during pre-*Kharif* and *Kharif* seasons

Well distributed rainfall during the year 2015 caused rapid infestation of broad-leaved weeds like *Trianthema* spp., *C. grandis, Celosia argentea* whereas infestation of grasses were at lower level compared to broad-leaved weeds. Huge down pour within short period especially during monsoon season of 2016 caused submergence which, in turn, reduced infestation of broad-leaved weeds and side by side increased invasion of grasses (**Figure 1**).

Weed dynamics during winter season

The results revealed that infestation of all weeds appeared during the winter season got reduced in successive years (**Figure 1**). This was mainly due to intervention of growing mixed cropping of berseem with gobhi sarson (*Brassica napus var. napus*), which has not only reduced emergence of weeds in berseem but also reduced seed bank potential of these weeds. Aggressive growth of berseem after 1st cut suppressed these weeds successfully. Removing *C. intybus* seeds by treating berseem seeds with 10% salt solution also reduced its infestation in berseem.

Weed management in different fodder crops

Mixed cropping of maize +cowpea

Results revealed that mixed cropping of maize (Variety '*African Tall*') + cowpea (Variety '*Bundel Lobia* 2') (50% seed rate of both the crops) reduced infestation of *Trianthema* sp. considerably.

Cowpea started to show smothering effect on weeds at 20-25 DAS. Mixed cropping not only reduced infestation of weeds but also provided balanced green fodder of cereal and legume combination to the cattle (**Figure 2** and **3**).

However, time of harvesting was very important to harness the benefit of green fodder production of maize + cowpea mixed cropping. The results revealed that maximum benefit was obtained when both the crop was harvested at 55 DAS at which both fodder maize and fodder cowpea have complementary effect on each other.

Beyond this stage cowpea showed supplementary effect up to 65 DAS and after that it became competitive to maize causing yield reduction to the tune of 19.4 and 37.3%, respectively, compared to the yield obtained at 55 DAS (**Figure 4**).

Replacement of fodder sorghum by fodder cowpea for controlling *Celosia argentea*

Celosia argentea was associated with fodder sorghum as it grew well within the canopy of sorghum and reached to the top of the canopy. It reached to the seeding stage much earlier than the harvest of green fodder sorghum. The fodder sorghum was severely infested with *Celosia argentea* and harvested green fodder sorghum contained large quantities of *Celosia argentea* which, in turn, reduced the quality of fodder sorghum. Intervention of turning the land to fodder cowpea (Variety '*Bundel Lobia* 2')

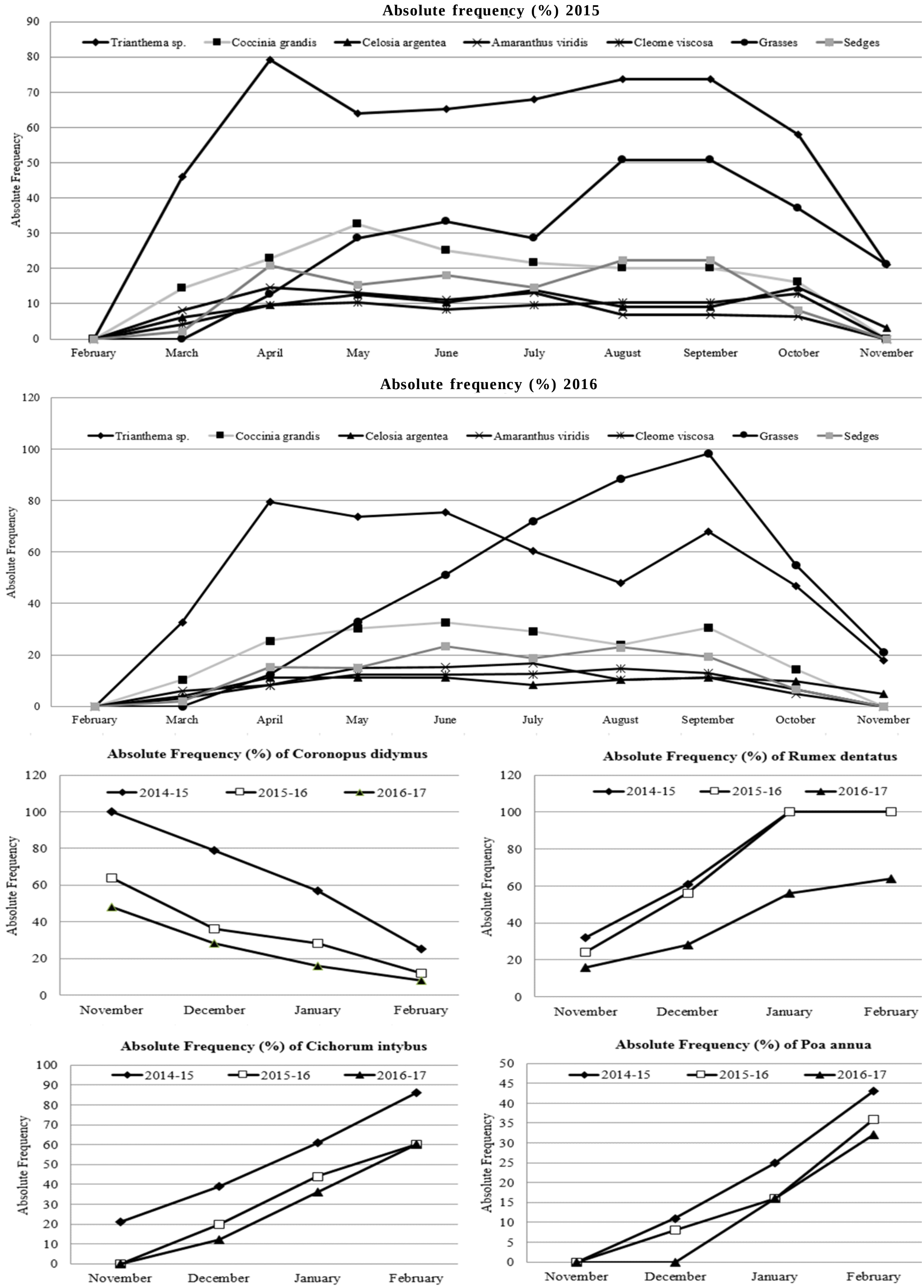


Figure 1. Weed dynamics in pre-*Kharif*, *Kharif* and winter seasons

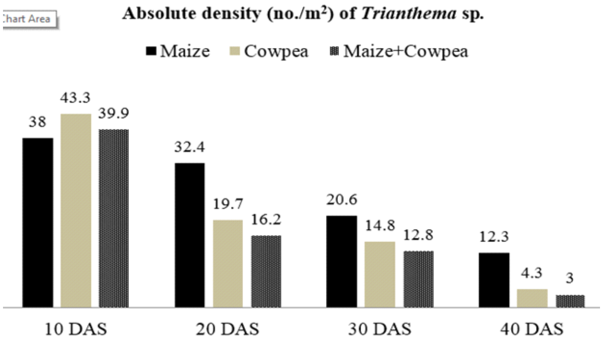


Figure 2. Absolute density (no./m^2) of *Trianthema* sp. at different days after sowing (DAS)

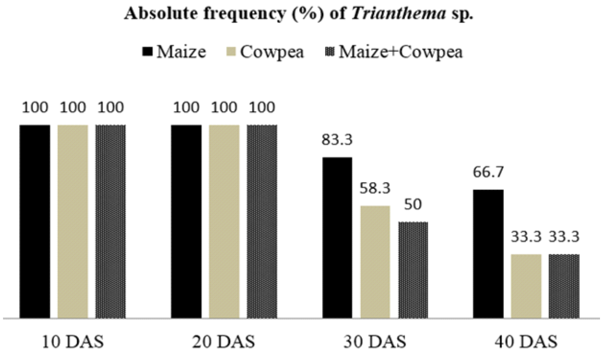


Figure 3. Absolute frequency (%) of *Trianthema* sp. at different days after sowing (DAS)

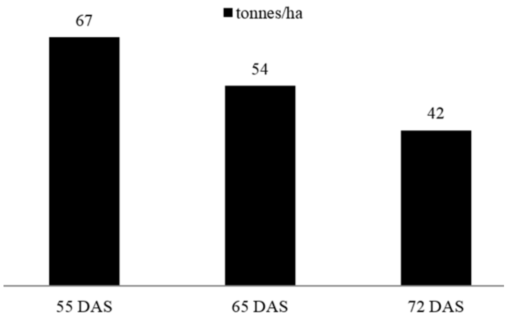


Figure 4. Green fodder yield (t/ha)

reduced population and seed production capacity of this weed. *C. argentea* usually produced on an average 2,606 seeds/plant when the weed was associated with fodder sorghum. Turning the land to fodder cowpea inhibited the growth and development of *C. argentea*, and finally hampered seed production of this weed. This was due to trailing and prostrate growth habit of cowpea. Almost 86% reduction in seed production of *C. argentea* due to turning the land to cowpea was recorded (**Figure 5** and **6**).

Mixed cropping of berseem and gobhi sarson (*Brassica napus* var. *napus*) for controlling *Coronopus didymus* in berseem

Growth of berseem was slow up to 1st cutting (up to 40 DAS). The weed *C. didymus* took the advantage of slow growth of berseem and flourished aggressively below the vegetative parts of berseem

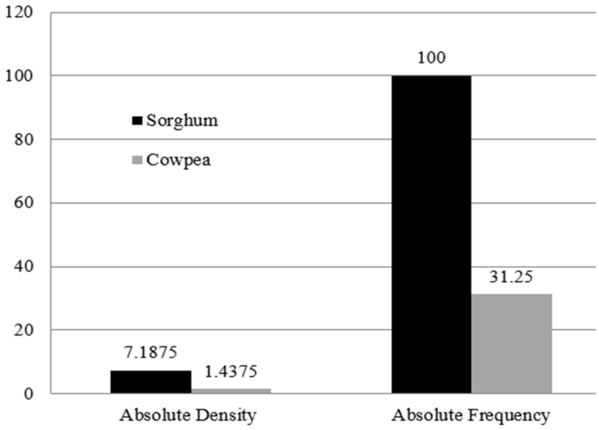


Figure 5. Distribution and population (no./m^2) of *Celosia argentea* in fodder sorghum and cowpea

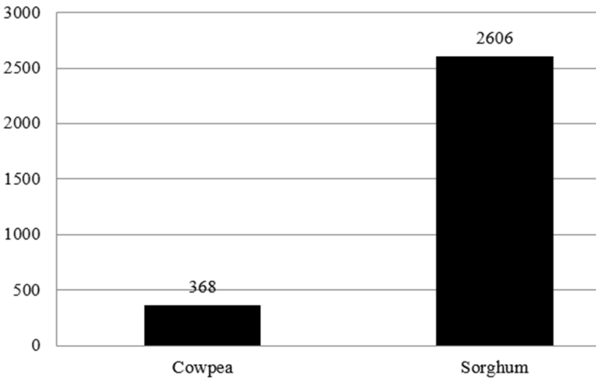
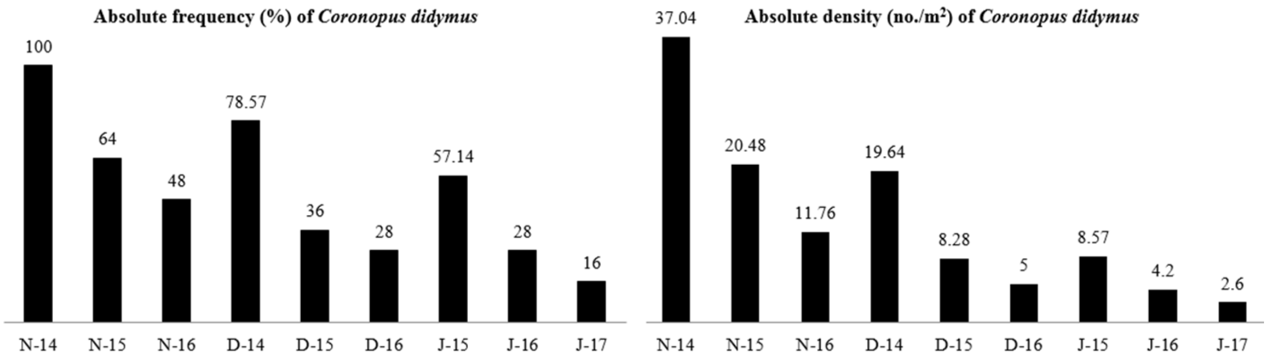


Figure 6. Average seed production capacity (no./plant) of *Celosia argentea*

along with the ground surface. Growing berseem + gobhi sarson (at the seed rate of 600 g/ha) as mixed cropping offered strong competition to *C. didymus* and prevented its growth and spread within berseem. This intervention reduced spread and population of the weed during winter seasons of 2015 and 2016 (**Figure 7**). Besides, gobhi sarson also compensated low green fodder yield of berseem during 1st cut.

Mixed cropping of berseem and rye grass in un-puddled soil for controlling *Coronopus didymus* in berseem

Coronopus didymus was highly prevalent in berseem with higher value of absolute density and 100% absolute frequency under puddled condition. Growing of berseem and rye grass as mixed cropping system with 50% seed rate of both the crop in un-puddled condition reduced the infestation of *C. didymus* at greater extent, which registered the absolute density (no./m^2) of 5.8 and absolute frequency of 33.3% during 1st cut at 56 DAS and absolute density (no./m^2) of 2.27 and absolute frequency of 20% at 41 days after 1st cut. This was mainly due to high tillering capacity, faster growth and rapid coverage of ground surface which, in turn,



(N-November, D-December, J-January, 14-2014, 15-2015, 16-2016, 17-2017)

Figure 7. Absolute density (no./m^2) and absolute frequency (%) of *Coronopus didymus*

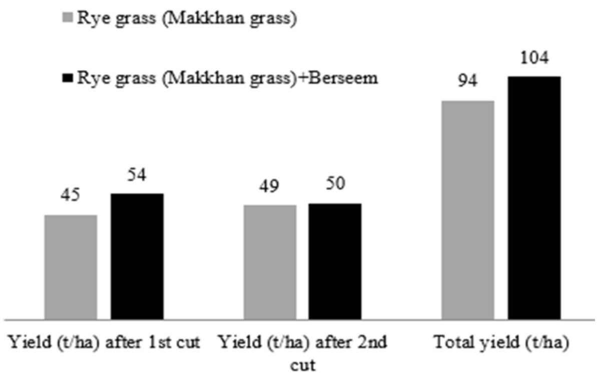


Figure 8. Green fodder yield (t/ha)

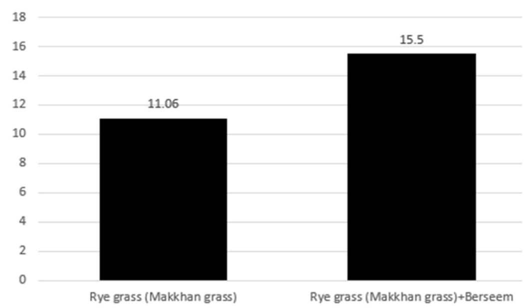


Figure 9. Crude protein content (%) at 2nd cutting

made the condition unfavourable for *C. didymus* as this weed preferred to grow along with the ground surface. Besides, the mixed cropping also produced higher amount of balanced green fodder (Legume + cereal) with desirable crude protein content (**Figure 8** and **9**).

Turing the berseem fields to oat cultivation and oat fields to berseem cultivation for controlling *Coronopus didymus*, *Rumex dentatus* and *Cichorium intybus*

Turing the berseem fields to oat cultivation and oat fields to berseem cultivation recorded lower values of absolute density and absolute frequency of the dominant weed flora and this was due to the breaking of cycle perpetuation of *C. didymus*, *R. dentatus* and *C. intybus*. Oat acted as a very good smother crop because of its fast tillering capacity and dense canopy development. Oat crop made the ecosystem completely unfavourable for growth and development of *Coronopus didymus*, *R. dentatus* and *C. intybus* (**Figure 10**).

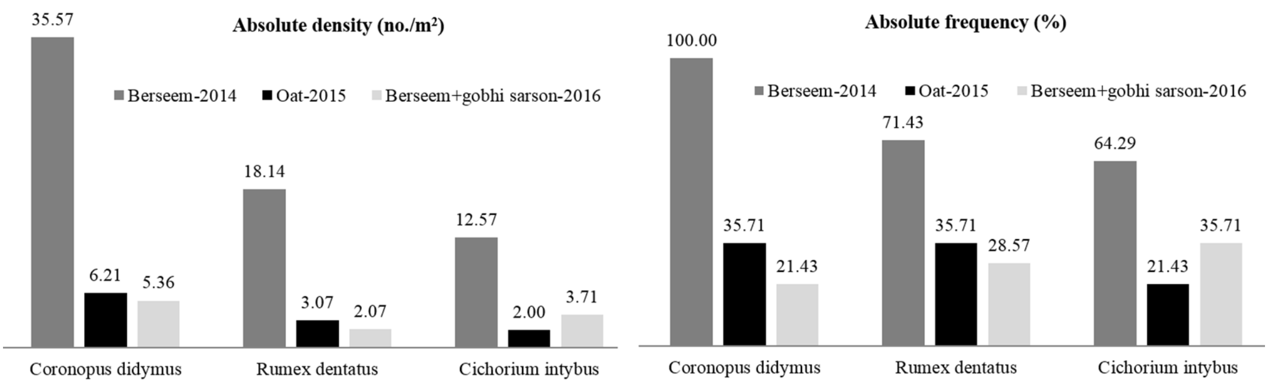


Figure 10. Reduction in weed population by turning the berseem field to oat cultivation and oat field to mixed cropping of berseem + gobhi sarson in succeeding year

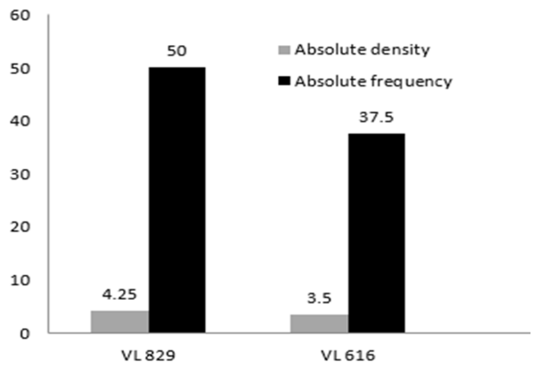


Figure 11. Absolute density (no./m^2) and absolute frequency (%) of *Phalaris minor* at 55 DAS

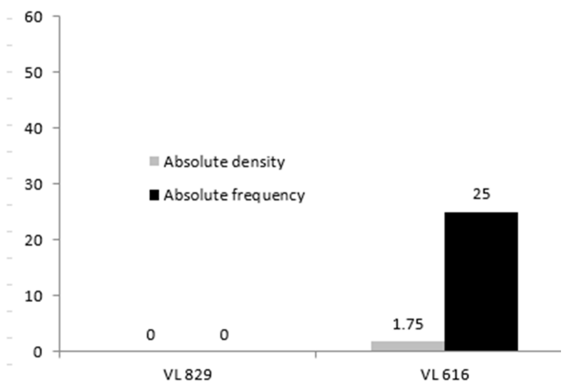


Figure 12. Absolute density (no./m^2) and absolute frequency (%) of *Phalaris minor* at 80 DAS

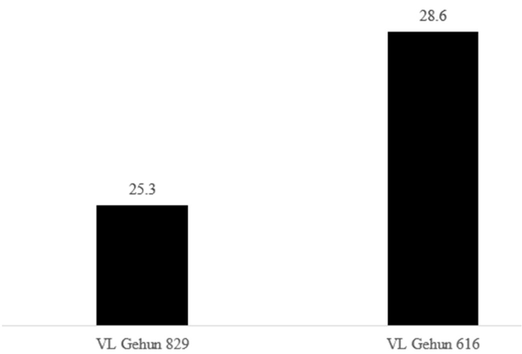


Figure 13. Green fodder yield (t/ha) at 57 DAS

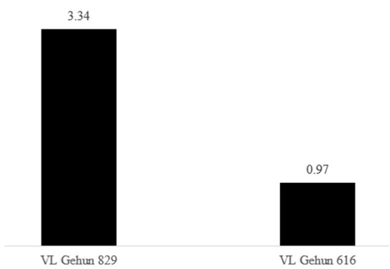


Figure 14. Grain yield (t/ha)

Control of resistant biotype of *Phalaris minor* by growing dual purpose wheat variety

Herbicide resistant *Phalaris minor* was recorded in wheat at the KVK farm of ICAR-IVRI, Izatnagar campus. The biotype showed resistant against the action of sulfosulfuron and clodinofop, however, it showed susceptibility against the action of pinoxaden. Apart from herbicide application for controlling resistant biotype, growing of dual purpose (Grain-cum-green fodder) wheat reduced infestation of resistant biotype after the 1st cut of wheat at 57 DAS for green fodder. High tillering capacity of dual purpose wheat after 1st cut suppressed the growth of *Phalaris minor* and the weed had lost the capacity to put forth the new growth (**Figure 11** and **12**). The variety '*V L Geghun* 829' has been found effective in terms of green fodder yield and grain yield (**Figure 13** and **14**). Higher number of panicle/m^2 contributed to the grain yield on account of 3.34 t/ha of the variety '*VL Gehun* 829'. Poor regeneration capacity of '*VL Gehun* 616' resulted in low grain yield of 0.97 t/ha**.** It has been observed that use of combine harvester led to the distribution of weed seeds (*Phalaris minor* and *Rumex dentatus*) throughout the field. The wind thrust ejected behind the combine harvester caused distribution of weed seeds throughout the field.

List of weeds appear in fodder and grain crops at Fodder Farm of ICAR-IVRI, Izatnagar

Grasses:

- *Cynodon dactylon* (in fodder maize during pre-*kharif* and *kharif* seasons)
- *Echinochloa colona* (in fodder maize, multi-cut sorghum and cowpea during pre-*kharif* and *kharif* seasons)
- *Echinochloa crusgalli* (in rice during *kharif* season)
- *Panicum maximum* (Non-crop area during *kharif* season)
- *Paspalum disticum* (in fodder maize and multi-cut sorghum during pre-*kharif* and *kharif* seasons)
- *Eleusine indica* (in fodder maize and non-crop area during pre-*kharif* and *kharif* seasons)
- *Digitaria longiflora* (in fodder maize, multi-cut sorghum and cowpea during pre-*kharif* and *kharif* seasons)
- *Digitaria ciliaris* (in fodder maize, multi-cut sorghum and cowpea during pre-*kharif* and *kharif* seasons)
- *Dactyloctenium aegyptium* (in non-crop area during pre-*kharif* and *kharif* seasons)
- *Sorghum halepense* (in non-crop area during pre-*kharif* and *kharif* seasons)
- *Setaria glauca* (in fodder maize during pre-*kharif* and *kharif* seasons)
- *Panicum repense* (in rice and non-crop area during *kharif* season)
- *Phalaris minor* (in wheat)
- *Poa annua* (in berseem and oat during winter season)

Sedges:

- *Cyperus rotundus* (in fodder maize, cowpea and non-crop area during pre-*kharif* and *kharif* seasons)
- *Cyperus esculentus* (in fodder sorghum and fodder maize during pre-*kharif* and *kharif* seasons)
- *Cyperus iria* (in rice and fodder sorghum during pre-*kharif* and *kharif* seasons)
- *Cyperus flavidus* (in rice during *kharif* season)
- *Cyperus pilosus* (in non-crop area during pre-*kharif* and *kharif* seasons)

Broad-leaved weeds:

- *Trianthema portulacastrum* (in fodder maize and cowpea during pre-*kharif* and *kharif* seasons)
- *Trianthema monogyna* (in fodder maize and cowpea during pre-*kharif* and *kharif* seasons)
- *Celosia argentea* (in fodder sorghum during pre-*kharif* and *kharif* seasons)
- *Ludwigia parviflora* (in rice during *kharif* seasons)
- *Ageratum conyzoides* (in fodder maize and non-crop area during pre-*kharif* and *kharif* seasons)
- *Cleome viscosa* (in fodder maize during pre-*kharif* and *kharif* seasons)
- *Physalis minima* (in fodder maize, wheat and mustard during winter season)
- *Amaranthus viridis* (in fodder maize and cowpea during pre-*kharif* and *kharif* seasons)
- *Commelina benghalensis* (in fodder maize during pre-*kharif* and *kharif* seasons)
- *Commelina diffusa* (in fodder maize during pre-*kharif* and *kharif* seasons)
- *Rumex dentatus* (in berseem, oat and wheat during winter season)
- *Cichorium intybus* (in berseem during winter season)
- *Coronopus didymus* (in berseem during winter season)
- *Spilanthes calva* (in berseem during winter season)
- *Chenopodium album* (in wheat, early summer multi-cut sorghum, mustard and cowpea)
- *Solanum nigrum* (in wheat and mustard during winter season)
- *Sonchus oleraceus* (in mustard during winter season)
- *Parthenium hysterophorus* (in non-crop area during pre-*kharif* and *kharif* seasons)
- *Cannabis sativa* (in non-crop area during pre-*kharif* and *kharif* seasons)
- *Medicago denticulate* (in berseem and non-crop area during winter season)
- *Melilotus alba* (in berseem during winter season)
- *Malva parviflora* (in non-crop area during winter season)

It has been concluded that *T. portulacastrum* and *T. monogyna* were widely distributed throughout the fodder farm and it was mainly due to its strong character on seed production and multiplication capacity. Ten days old plant of *Trianthema* sp. could be controlled through stale seedbed technique and beyond that stage fragmented plant parts had shown the capacity to put forth the new growth. Cowpea (Variety '*Bundel Lobia* 2') showed significant effect in minimising distribution and seed production capacity of *C. argentea.* Mixed cropping of maize (Variety '*African Tall*') and cowpea (Variety '*Bundel Lobia* 2') controlled *Trianthema* spp. and maximum green fodder yield was obtained at 55 days after sowing beyond that cowpea showed competitive effect on maize. Mixed cropping of berseem (Variety '*Wardan*') and gobhi sarson (*B. napus* var. *napus*) reduced infestation of *C. didymus* and mixed cropping of berseem (Variety '*Wardan*') and rye grass (Variety '*Makkhan Grass*') in un-puddled condition also reduced infestation of *C. didymus* at greater extent. The mixed cropping produced higher amount of balanced green fodder (Legume + cereal) with desirable crude protein content. Growing of dual purpose (Grain-cum-green fodder) wheat variety '*VL Gehun* 829' reduced infestation of herbicide resistant biotype of *Phalaris minor.*

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Assessment of soil fertility using *Ageratum conyzoides* in mid-hills of Arunachal Pradesh

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ABSTRACT

Growers of the hill ecosystem, assess soil fertility by visualizing the luxuriant growth of weeds (*Ageratum conyzoides*). Since a long time, they have been using this as a soil fertility indicator as indigenous knowledge. Thus, the present study was conducted to quantify weed density, crop performance, soil fertility status and correlate with growers view by enquiring from respondents. A total of 78 respondents were interviewed and their responses were filled in unorganized questioners. The major parameters *viz.* weed density, rice grain yield and chemical properties of soil were considered in this study. It was found that growers of the area have strong indigenous perceptions for assessment of soil fertility. Higher density, better rice grain yield and chemical properties of soils were found better indicator of soil fertility as per grower's perceptions.

INTRODUCTION

Agriculture in the mid-hill conditions is characterised by the close relationship between crop production, livestock, forestry and fisheries. Forest trees and crops provide fodder and bedding materials for livestock, which provides animal protein and manures. In wetland rice cultivation (*pani kheti*), fertility status is maintained by leaving crop residues in-situ, supplying manures and forest litter wash from the hill slopes (Choudhary *et al.* 2012). Efforts have not been done to maintain or enhance the soil fertility status in mid-hill conditions, however, site-specific soil and water conservation measures are being given paramount importance. There is a limited document available which shows the long-term fertility status of the soil with respect to traditional cropping system and management practices imposed. The adoption level of improved techniques has been limited mainly due to inadequate extension system. Even though extension services are provided to stakeholders, regardless of the size of their farm land, they thought them to be inadequate, because of not meeting their specific requirements (Benjamin 2013).

Farmer's knowledge on soil fertility has been ignored completely, but due to participatory research, it becomes clear that the indigenous knowledge of farmers on soil fertility has a well developed ability. Their knowledge on differentiating fields on same vicinity/farms is fool proof. Farmers use many criteria to judge the soil fertility of their farm, including economic and ethnic influences, to categorize their soils, but weed density, diversity and health of the weeds are main criteria to decide the soil fertility. Growers of the hill ecosystem, assess soil fertility by visualizing the luxuriant growth of *Ageratum conyzoides*. However, the negative effect of *Ageratum conyzoides* had also been reported by researchers that it reduced the crop yield (Kohli *et al.* 2006), yield reduction and high labour inputs in maize (Wezel *et al.* 2000), alternative host of a number of pathogens and nematodes. It also releases some allelochemicals that could inhibit the growth of other species (Dogra *et al.* 2009).

As such, they assess the fertility of the soil using a wide range of indicators which they can see or feel, including crop yields, soil depth, drainage, moisture content, manure requirements, water source, slope, and weed abundance (Desbeiz *et al.* 2004). However, researchers were more focused on a few criteria like soil nutrient status or physical properties of the soil on deciding the soil fertility. In order to know the actual fertility status of the soil and farmer's perceptions and assessment of soil fertility were studied to prove indigenous knowledge on soil fertility judgment by farmers of mid-hill condition of Arunachal Pradesh.

MATERIALS AND METHODS

The study was conducted from 2010 to 2012 in 13 villages of two districts West Siang and Upper Subansiri of Arunachal Pradesh in wet land rice (*pani kheti*). The altitude of the study area varied from 550 to 950 m above mean sea level (with 5-10% of slope). Majority of the household were engaged in rice cultivation during the rainy season. The farming system consists of compartmental bunding with lowland irrigated or partially irrigated leveled field (*pani khet*) and terrace lowland. These lands are owned by villagers and grow rice by own or giving on rent.

A random sampling method was employed to select the sample of farmers from the study area. A total of 78 respondents/farmers were selected from 13 villages at random and enquired their perception on soil fertility status. Six key informants from each village were gathered at the field and as per their perceptions, scores were given. Farmer's perceptions on soil fertility status were ranked from high, medium and low. After interviews, during March- April soil samples were collected from respective fields of 20 cm depth (plough depth). The farmer's judgments of only a few parameters were taken into considerations; those were a) density of *Ageratum conyzoides*, b) soil colour, and c) rice productivity. The details of said parameters which were used for comparison are given in **Table 1**. In the study area, there was not much deviation observed in rice cultivation practice except varietal differences.

The perceptions of 78 respondents were taken into consideration and information was used to assess the fertility status of their fields. Modified farmers' indicators were used as suggested by Desbeiz *et al.* (2004) and classified based on their perceptions: Soil characteristic indicators (soil properties which the farmers felt characterised high, medium or low fertile soils). Crop performance indicators (crop characteristics mainly yield reflecting soil fertility status). Biological indicators (density of *Ageratum conyzoides* reflected soil fertility status).

Decision/assessment	Indicators used
What is the current soil fertility?	Soil colour, crop yield, weeds
What potential does this field have?	Water retention ability, crop yield, weeds
Is the soil management strategy in this field working?	Soil colour, crop yield, weeds
How is the current crop performing?	Crop yield, weed growth

For the analysis of soil chemical properties, soil pH was determined by a pH meter after extraction from a 1: 2.5 ratios of soil and water. Organic carbon (OC) was estimated using the Walkley and Black dichromate method, and available nitrogen (N) using the standard micro-digestion method (Kjeldahl). For available phosphorus (P_2O_5) determination, the Bray and Kurtz method (0.03M NH_4F/0.1M HCl extraction) was used. Exchangeable potassium (K_2O) was estimated by 1M ammonium acetate extraction followed by flame photometric determination. The N, P_2O_5 and K_2O status was compared from **Table 1**. The different parameters of the studies were analyzed using SAS Version 9.3 (SAS Institute Inc., Carry NC USA).

RESULTS AND DISCUSSION

Socio-economic status

The demographic, socio-economic and land characteristics of the farmers interviewed are presented in **Table 2**. The majority of the respondents were male (88.5%), with an average age of 42.5 years, and had the cropping experience of 19 years. The main source of the income (84.6%) was sold by farm produce. Crops were only grown during the rainy season and kept the land fallow throughout the year. During the period, weed flora was allowed to grow and later incorporated into the soil in the month of April. Simultaneously, the second flush of weeds was also allowed to grow and again incorporated at the end of May. Later, the fields were inundated with water. However, few of the farmers also go for third turning just before transplanting. In the rainy season, fields were irrigated through locally developed irrigation channels. These channels were diverted from nearest tributaries well ahead of the field (1-2 km ahead) and channeled to their field. Once water enters into the cropping area, it passed as per slope of the field and excess water drains out from another end of the field.

Soil fertility indicators

Among the different characteristics, respondents were asked to rank the principal indicators most appropriate deciding soil fertility status, the majority were cited crop yield (96%), followed by soil colour (93%) and weed growth (90%). However, some of the farmers also ranked water availability (68%) in the field. Therefore, overall there was a strong accord between the farmers' assessment of fertility status of the soil and the indicators that they had said in the interviews, which they were used to assess soil fertility. There was, however, considerable variation between individual farmers in the indicators used. It became

Table 1. Criteria for classification of weed density, soil fertility and rice grain yield

Particular	Soil colour	*Ageratum conyzoides* density (no./m^2)	N	P_2O_5 kg/ha	K_2O	Rice yield (t/ha)
Low	Yellowish brown	<25	<280	<10	<270	<1.5
Medium	Brown	25-50	280-400	10-15	270-350	1.5-3.0
High	Dark brown to black	>50	>400	>15	>350	>3.0

Table 2. Demographic and socio-economic characteristics of the sampled farmers in thirteen villages with two districts in the Arunachal Pradesh

Variables	Respondents (n=78)
Farmers gender (%)	
Females	11.5
Males	88.5
The average age of respondents (years)	42.5
Farmer's education (%)	
Higher Secondary	9.2
High School	14.1
Middle School	18.0
Primary School	25.5
None	33.2
Average family size	5.5
The main source of income (%)	
Agriculture (sale of farm produce)	84.6
Government servant	11.5
Business	3.9
Cropping experience (years)	19.0
Average farm size (ha)	
Wetland	1.2
Upland	1.5

clear from the discussions that farmers use soil fertility indicators to assess soil fertility and make soil management decisions. However, farmers of the area use more than one indicator to decide or assess the soil fertility status. Some of the respondents use number of criteria to decide, but in the study, factors were pre-decided as per the perceptions of large group voice. The overall pattern of judging the soil fertility of 13 villages was the same. Farmers of the area hardly supply inputs into the soil, therefore, indigenous knowledge on measuring soil fertility status play a crucial role to better crop harvest.

Rice grain yield and weed density

Respondent has given the ranking of soil fertility by seeing the weed coverage. These were counted and categorized, and found that the *Ageratum conyzoides* density into high fertile soils was >50 plants/m^2, and medium fertile soils had 25-50 plants/m^2, whereas, low fertile soils had <25 plants/m^2. Rice grain and *A. conyzoides* density were highest in black to brown coloured soil (3.0-3.5 t/ha and 40-72 no./m^2, respectively) followed by brown soil (1.5-2.9 t/ha and 31-63 no./m^2, respectively). However, the lowest rice grain yield and *A. conyzoides* density were measured in yellowish to brown soil (0.9-1.4 t/ha and 11-31 no./m^2, respectively). It was also noticed a few outliers in yellowish to brown coloured soil. The average rice grain yield and density of *A. conyzoides* were noticed with 2.41 t/ha and 38.8 no./m^2, respectively (**Table 3**).

Rice grain yield followed the linear relationship with weed density and soil moisture content with a coefficient of determination of 0.77 and 0.81, respectively (**Figure 1a and b**). These clearly showed that there was a positive association between rice grain yield with weed density and soil moisture content. Soil moisture content was more linear with the positive association and this gave the better association with rice yield. The overall moisture content of the soils was recorded with 23.7% (**Table 3**). A similar finding was also corroborated by Choudhary (2017).

Table 3. Weed density, chemical properties of the soil and rice yield in the study area (n=78)

Particular	Mean	Low	Medium	High
		% respondent		
Weed density (no./m^2)	38.8±12.25	17.9	46.2	35.9
Soil moisture content (%)	23.7±3.22	53.8	28.2	17.9
pH	5.44±0.26	-	-	-
Available N (kg/ha)	284.2±80.18	18.0	41.0	41.0
Available P_2O_5 (kg/ha)	10.9±2.18	17.9	42.3	29.7
Available K_2O (kg/ha)	314.0±49.13	23.1	35.9	41.0
Crop yield (t/ha)	2.41±0.72	16.7	55.1	28.2

SD: standard deviation (±)

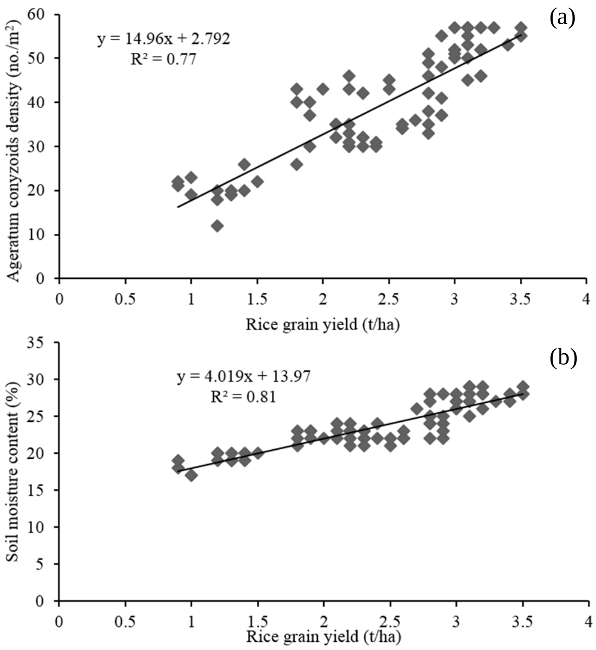

Figure 1. The relationship between rice grain yield and a) *A. conyzoids* density/m^2, and b) soil moisture content (%)

It was recorded that among the soil colour rank assigned, black to deep brown and brown colour comes under high fertile soil. Whilst, in medium fertile soils all three-group black to deep brown, brown and yellowish brown soil colour was noticed, and low fertile soils have only yellowish brown coloured soil.

Nutrient status of soil

The results of chemical analysis of the sampled fields are shown in **Table 3**. The pH of most of the soil varied from 5.0-5.8 indicating acidic in nature corresponding to another mid hill area (Choudhary and Kumar 2015). The average pH of the soils was recorded of 5.44. Nitrogen levels were medium in range (284.2 kg/ha), average available P_2O_5 was recorded of low levels with 10.9 kg/ha and available K_2O was estimated intermediate to a high level (314.0 kg/ha). It was measured that productive soils have more of available N, P_2O_5 and K_2O and *vice-versa* with low productive soil. There was a strong correspondence between the farmer's assessment of soil fertility and the measured soil chemical characteristics. Respondents described as high fertile soils were found on higher values of available N, P_2O_5 and K_2O, and considerably higher soil pH. However, the majority of the factors are interrelated, hence, these were not independent.

Similar to rice grain yield, weed density was correlated with chemical parameters, weed density has followed the positive linear relationship with soil pH with R^2=0.73, available N, R^2=0.79, available P_2O_5, R^2=0.76 and available K_2O, R^2=0.61 (**Figure 2a, b, c** and **d,** respectively). Inference can be drawn from **Figure 2** that near the neutral pH, there was better availability of soil nutrient and more the weed density.

In a large chunk of the area, low soil fertility is a major hindrance in crop production. However, it's not a universal problem and some other factors may also responsible for lesser crop production. Weeds, compete with the crop for various resources if both were growing together, but, if weeds are alone in the field then there is no question of competition, the majority of plant nutrients are being taken up by weeds and with incorporation, nutrients were returned into the soils (Roder *et al.* 1995). It was also noticed that *Ageratum conyzoides* has strong and deep root system which may mine the nutrients from the deeper soil.

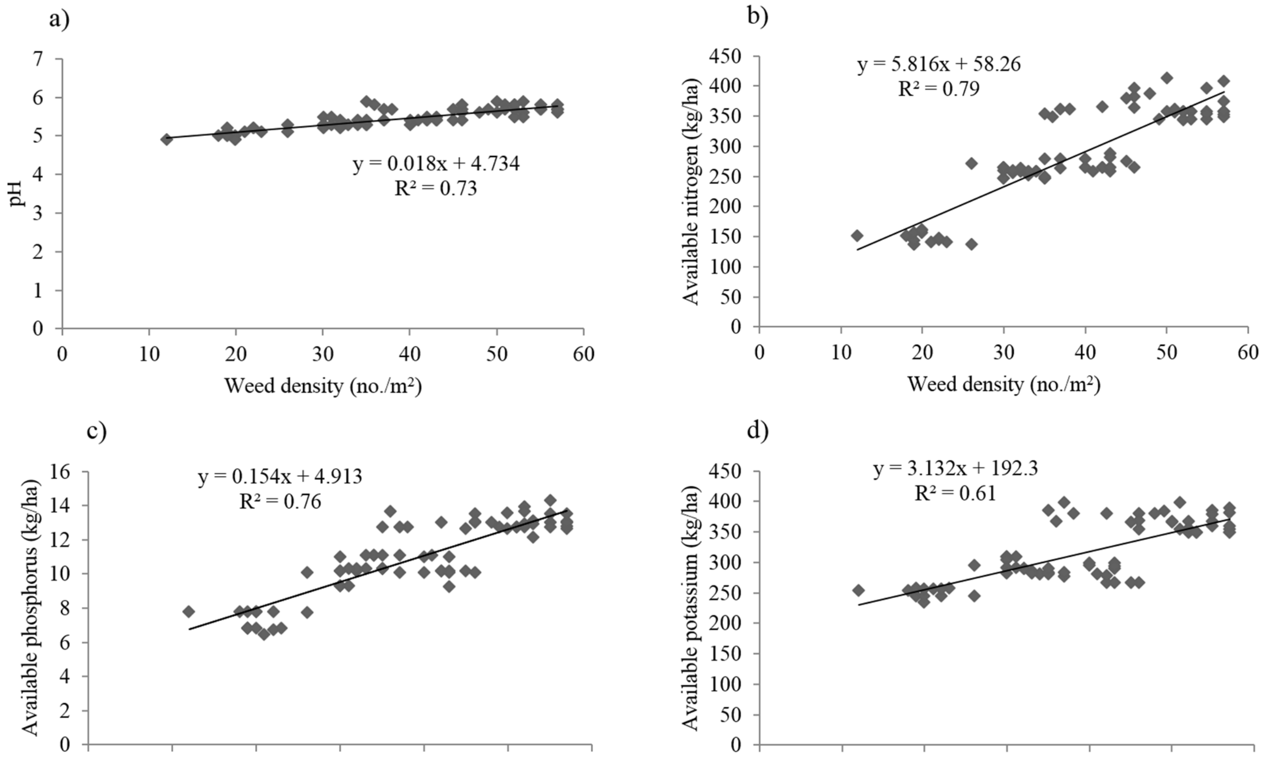

Figure 2. Relationship between density of weeds (*Ageratum conyzoides*) and chemical properties of soil a) pH, b) available nitrogen, c) available phosphorus and d) available potassium

The biomass of the fallow vegetation generally represents the major pool for N, P, K, Ca and Mg (Andriesse and Schelhaas 1987). Removal of vegetation had irreversible loss of nutrients, whereas incorporation certainly increases the availability. Trehan *et al.* (2008) reported that the response of crop residues was visible only after second year onwards. Incorporation of residues increased the NPK use efficiency by 14 and 15% in potato and by 22 and 27% in onion during second and third years, respectively.

Desbeiz *et al.* (2004) have reported that *Ageratum conyzoides, A. houstonianum,* and *Galinsoga parviflora* were important weed species which predominantly grow in fertile soil. Fertile soils have more of plants from compositeae family and less fertile soils have more plants from poaceae family *(Digitaria sanguinalis, Imperata cylendrica* and *Cynodon dactylon)*.

The correlation coefficient in **Table 4** depicts the degree of association between two variables. The study demonstrated that yield with six independent variables with 78 observations had shown a positive correlation with each other. The correlation coefficient of the majority of the parameters was significant at 1% level of significance. However, soil moisture has shown significant at 5% level of significance with weed density, whereas potassium has non-significant with weed density at a tested level of significance.

The findings confirmed the indigenous knowledge of farmers that higher density of *Ageratum conyzoides* results in higher rice grain yield and improved soil fertility.

Table 4. Correlation of different variables with respect to yield

Particulars	Weed density	Soil moisture	pH	Nitrogen	Phosphorus	Potassium
Weed density	1.00					
Soil moisture	0.27*	1.00				
pH	0.41**	0.34**	1.00			
Nitrogen	0.43**	0.61**	0.60**	1.00		
Phosphorus	0.29**	0.42**	0.56**	0.71**	1.00	
Potassium	0.21	0.52**	0.62**	0.73**	0.66**	1.00

*Significant at 5%; **significant at 1%

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Utilization of water hyacinth as livestock feed by ensiling with additives

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ABSTRACT

Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is one of the most productive plants on earth, but it is also considered as the world's worst aquatic weed. An experiment was carried out with the objective of utilizing it by converting to silage for its usage as animal feed. The quality and palatability of water hyacinth silage prepared with additives such as molasses, cassava powder, and rice bran were assessed. The completely randomized design (CRD) with 12 treatment combinations and 3 replications, was used. The treatments included: combination of wilted and fresh water hyacinth with or without rice straw or guinea grass and using any of the additives such as molasses, cassava flour and rice bran. Wilted water hyacinth plus cassava powder (10%), wilted water hyacinth plus rice straw (10%) plus cassava powder (10%), and wilted water hyacinth plus guinea grass (10%) plus cassava powder (10%) had good fodder quality due to low pH. The odour of these combinations was rated as either 'good' or 'very good'. The quality of rice bran added silages was low in terms of pH, odour and palatability; although its nutritional quality was high. Rice bran enhanced crude protein, crude fat and ash content of silages. Molasses ensured the quality of silage by lowering pH and enhancing intake. Cassava powder addition in general reduced the pH of the silage and enhanced the palatability of silage.

Most aquatic weeds interfere with the normal functioning of water bodies, besides causing several harms to the environment. Among the aquatic weeds, *Eichhornia crassipes* (Mart.) Solms, commonly known as water hyacinth is considered as the world's worst aquatic weed. It is estimated that 20-25 per cent of the total utilizable water in India is infested with water hyacinth alone (Varshney *et al.* 2008). Recognized by its lavender flowers and shinning bright leaves, water hyacinth is prolific in growth and is one of the most productive plants on earth. The plant can tolerate both fresh and saline water (AERF 2005); hence, its spread knows no boundaries. The plant is also a serious threat to biodiversity as it prevents the growth of other aquatic plants. It adversely affect water sources by blocking canals and motor pumps in irrigation projects (Jayan and Sathyanathan 2012), providing convenient breeding sites for mosquito, and interfering with fishing and fish culture.

In the past, several methods were tried to prevent its proliferation and spread (Bindu and Ramasamy 2005), but all these have not proved much because of its survival strategies. An alternate option is to utilize water hyacinth for various purposes such as fibre, animal feed, and manure (Jafari 2010). Silage for feeding animals is such an option. Livestocks are reluctant to eat water hyacinth in fresh form. Tham (2012) reported that improved silage could be made from water hyacinth by the use of additives such as molasses and rice bran. Molasses is a universal additive to silage but not easily available to common people. Lowilai *et al.* (1993) reported the use of cassava flour instead of molasses. Little bag silage in polythene bags is a viable option for small holders as traditional silos such as bunker, trench or tower silos are not feasible for them (Lane 2000). Having considered all the possible options, an experiment was designed and conducted to explore the possibility to utilize water hyacinth as a feed for ensiling, especially suited to small holders.

MATERIALS AND METHODS

The experiment was carried out at the College of Horticulture, Vellanikkara, Thrissur and University Livestock Farm and Fodder Research Station, KVASU, Mannuthy during August to October 2016. The experiment was done using completely randomized design (CRD) with 12 treatment combinations and 3 replications. The treatments included combination of wilted and fresh water hyacinth with or without rice straw or guinea grass and using any of the additives such as molasses, cassava flour and rice bran (**Table 1**).

Considering the ease and manoeuvrability, fresh water hyacinths were collected and piled up for some time to drain out dripping water. The petioles and leaves of these plants were chopped in to 4-5 cm pieces, spread on plastic sheets and allowed to wilt in shade for two days. Depending on treatments, grass, rice straw and additives were added and thoroughly mixed. Afterwards, these were filled in little bags made of polythene at the rate of 5 kg/cover. The mixtures were compressed by hand to remove as much air as possible. The covers were tightly tied and stored indoors. All the covers were opened after 45 days. The colour and smell of silages thus obtained were noted immediately after the experimental bags were opened by employing volunteers. Representative silage samples were taken for later analysis.

Dry matter content of the ensiled water hyacinth was determined after oven- drying at 80 ± 5ÚC for 12 hours. Nitrogen content of silage was estimated by Micro Kjeldahl digestion and distillation method (Jackson, 1958). The nitrogen content thus obtained was multiplied by 6.25 to get the crude protein content of the plant samples. Crude fibre was estimated using acid-alkali digestion method (Sadasivam and Manickam 1992). The ether extract, ash content and silica content were analysed as described by AOAC (1990).The ether extract, which represents the crude fat fraction of the sample, was estimated by extracting the plant fat using petroleum benzene. The ash content in the samples was determined by igniting a known quantity of plant sample at 600ÚC for three hours. Nitrogen free extract was estimated by subtracting the crude protein, crude fibre, ether extract and ash content from 100. The palatability of silage was studied using 12 test animals. Silage treatments were fed as the first meal of the day and the feed intake was noted. The intake measurements consisted of two days for adaptation to the diets and three days for feed intake measurements. The animals were allowed to feed on a given weight of silage (W_1) and after 15 minutes the weight of left over feed (W_2) was noted. Then the percentage left over was worked out by the formula, percentage of left over feed = (W_2/W_1) x100.

RESULTS AND DISCUSSION

Physical quality parameters

In all the treatments, the silage was ready to use after 45 days. A main quality criteria of silage is pH, and based on pH, silage is generally classified as very good (pH 3.8 to 4.2), good (pH 4.2 to 4.5), and fair silage (pH >4.5) (Thomas 2008). In this experiment, wilted water hyacinth along with cassava powder (10%) seems to have good quality as it showed pH of 4.19 (**Table 1**). The odour of this silage was rated 'very good'. All the treatments with 10 per cent cassava powder showed low pH values. Quality wise, rice bran added silages were poor in terms of pH values, which were above 6.36. The results revealed that wilted water hyacinth plus cassava powder (10%), wilted water hyacinth plus rice straw (10%) plus cassava powder (10%), and wilted water hyacinth plus guinea grass (10%) plus cassava powder (10%) are almost equal in quality with respect to pH. The odour of these combinations was rated either 'good' or 'very good'. Rice bran added silages in general had bad odour. Among the fresh water hyacinth combinations, only those with rice straw (10%) and cassava powder (10%) proved good in terms of pH. The colour varied based on the ingredients used, mostly brownish green or grey.

Silage fermentation is affected mostly by water soluble carbohydrate content (Liu *et al.* 2011). Rice bran had 53 g water soluble carbohydrate per kilogram dry matter whereas molasses contains 700 g water soluble carbohydrate per kilogram dry matter (Lowilai *et al.* 1994; McDonald *et al.* 2011). Ngoan *et al.* (2000) stated that fermentation will be enhanced more by molasses than rice bran. As pH is a good indicator of fermentation, high pH of rice bran added silages may be due to the slower fermentation. Zanine *et al.* (2010) obtained low pH silage with cassava scrapings. Cassava scrapings (a by-product from the flour milling industry) at 7 per cent level improved the fermentation of elephant grass silage due to the high level of soluble carbohydrates and dry matter concentration and the pH of the silage was within the ideal range (3.8±0.12). Good quality silage has a characteristic yellowish green to brownish green colour (Gallaher and Pitman 2000) depending upon silage material and has pleasant, sour and sweet smell (Thomas 2008).

Chemical quality of the silage

The additives used influenced the chemical composition of water hyacinth silage (**Table 2**). Crude protein content gives an approximate value of protein content in forages. Among the treatments,

Table 1. Effect of additives on quality of water hyacinth silage

Treatment	pH	Colour	Odour
Wilted water hyacinth + molasses (5%)	4.53[d*]	dark brown	good
Wilted water hyacinth + cassava powder (10%)	4.19[d]	brownish green	very good
Wilted water hyacinth + rice bran (10%)	6.36[b]	greenish brown	bad
Fresh water hyacinth + rice straw (10%) + molasses (5%)	5.44[c]	golden yellow	very good
Fresh water hyacinth + rice straw (10%) + cassava powder (10%)	4.37[d]	grey	good
Fresh water hyacinth + rice straw (10%) + rice bran (10%)	6.58[b]	brown	bad
Wilted water hyacinth + rice straw (10%) + molasses (5%)	7.15[b]	dark brown	bad
Wilted water hyacinth + rice straw (10%) + cassava powder (10%)	4.38[d]	grey	good
Wilted water hyacinth + rice straw (10%) + rice bran (10%)	8.30[a]	brown	good
Wilted water hyacinth + guinea grass (10%) + molasses (5%)	6.36[b]	brownish green	good
Wilted water hyacinth + guinea grass (10%) + cassava powder (10%)	4.24[d]	grey	very good
Wilted water hyacinth + guinea grass (10%) + rice bran (10%)	7.24[b]	greenish brown	bad
LSD (p=0.05)	0.90		

*In a column, means with common letters do not differ significantly at 5% level in DMRT

Table 2. Effect of additives on the chemical composition of water hyacinth silage

Treatment	Crude protein (%)	Crude fibre (%)	Ether extract (%)	Nitrogen free extract (%)	Total ash (%)
Wilted water hyacinth + molasses (5%)	8.06[d*]	16.81[f]	0.53[f]	54.77[b]	19.84[b]
Wilted water hyacinth + cassava powder (10%)	7.15[e]	17.90[e]	1.39[c]	58.94[a]	14.63[e]
Wilted water hyacinth + rice bran (10%)	8.14[d]	22.04[bc]	1.81[a]	47.33[e]	20.68[b]
Fresh water hyacinth + rice straw (10%) + molasses (5%)	5.43[g]	20.86[d]	0.72[e]	52.53[cd]	20.46[b]
Fresh water hyacinth + rice straw (10%) + cassava powder (10%)	4.86[g]	22.25[b]	1.08[d]	54.31[b]	16.97[d]
Fresh water hyacinth + rice straw (10%) + rice bran (10%)	9.72[b]	25.35[a]	1.62[b]	41.06[g]	22.79[a]
Wilted water hyacinth + rice straw (10%) + molasses (5%)	6.56[f]	20.98[d]	0.55[f]	53.56[bc]	18.35[c]
Wilted water hyacinth + rice straw (10%) + cassava powder (10%)	7.85[d]	22.07[bc]	1.04[d]	54.84[b]	14.20[e]
Wilted water hyacinth + rice straw (10%) + rice bran (10%)	9.34[bc]	24.62[a]	1.54[bc]	43.62[f]	20.89[b]
Wilted water hyacinth + guinea grass (10%) + molasses (5%)	9.14[c]	20.61[d]	0.58[ef]	51.58[d]	18.09[cd]
Wilted water hyacinth + guinea grass (10%) + cassava powder (10%)	8.88[c]	21.23[cd]	1.09[d]	54.20[b]	14.60[e]
Wilted water hyacinth + guinea grass (10%) + rice bran (10%)	10.45[a]	22.87[b]	1.65[b]	44.64[f]	20.39[b]
LSD (p=0.05)	0.58	0.87	0.16	1.55	1.18

*In a column, means with common letters do not differ significantly at 5% level in DMRT

wilted water hyacinth + guinea grass (10%) + rice bran (10%) had the highest crude protein content (10.45%) followed by fresh water hyacinth + rice straw (10%) + rice bran (10%), and wilted water hyacinth + rice straw (10%) + rice bran (10%). Jones and Jones (1996) reported that absorbents rich in fibre such as straw reduce the nutritive quality during the ensiling process. Among the absorbents used, rice bran enhanced the crude protein significantly. As cassava contains low protein, those treatments with cassava powder showed the lowest crude protein content. Low crude protein and crude fibre content with the addition of cassava scrapings were reported by Zanine *et al.* (2010).

Crude fibre content was the highest in silages added with rice straw and guinea grass. Rice bran addition also enhanced the crude fibre content. The highest crude fibre content of 25.35% was recorded in the treatment, *viz.* fresh water hyacinth + rice straw (10%) + rice bran (10%) which was on par with wilted water hyacinth + rice straw (10%) + rice bran (10%) with a crude fibre content of 24.62 per cent. The lowest crude fibre content was observed in the treatment wilted water hyacinth + molasses (5%). Rice bran addition positively influenced the crude fat content of the silage. Wilted water hyacinth + rice bran (10%) had the highest crude fat content (1.81%) followed by wilted water hyacinth + guinea grass (10%) + rice bran (10%) and fresh water hyacinth + rice straw (10%) + rice bran (10%). Li *et al.* (2007) reported higher crude protein and crude fat by the addition of wheat bran.

Nitrogen free extract represents the digestible carbohydrate content. As cassava tubers are rich in carbohydrate content, it gave significantly high nitrogen free extract. Maximum NFE of 58.94 per cent was noted in the treatment, *viz.* wilted water hyacinth + cassava powder (10%). Ash content

Table 3. Palatability of silage

Treatment	Left over feed (%)		
	1st day	2nd day	3rd day
Wilted water hyacinth + molasses (5%)	55.24	0.00	0.00
Wilted water hyacinth + cassava powder (10%)	49.81	0.00	0.00
Wilted water hyacinth + rice bran (10%)	99.62	46.61	0.00
Fresh water hyacinth + rice straw (10%) + molasses (5%)	56.20	25.76	0.00
Fresh water hyacinth + rice straw (10%) + cassava powder (10%)	89.39	72.98	76.77
Fresh water hyacinth + rice straw (10%) + rice bran (10%)	96.71	95.02	87.35
Wilted water hyacinth + rice straw (10%) + molasses (5%)	85.66	78.95	61.89
Wilted water hyacinth + rice straw (10%) + cassava powder (10%)	0.00	0.00	0.00
Wilted water hyacinth + rice straw (10%) + rice bran (10%)	88.45	79.86	72.30
Wilted water hyacinth + guinea grass (10%) + molasses (5%)	87.35	54.75	0.00
Wilted water hyacinth + guinea grass (10%) + cassava powder (10%)	96.97	0.00	0.00
Wilted water hyacinth + guinea grass (10%) + rice bran (10%)	99.62	38.64	29.28

represents the mineral content of the silage. Rice bran addition significantly increased the ash content of the silage.

Palatability of silage

When considering the quality of silage, palatability of the product is an important criterion. Estimated palatability of silage as percentage of left over feed is given in **Table 3**. The silage combinations with low pH values were preserved well and had high palatability values. Rice bran addition reduced the palatability although its nutritional content was high. Cassava powder added silages have shown high palatability. On the first day of trial, there was only one treatment, *viz.*, wilted water hyacinth + rice straw (10%) + cassava powder (10%) with zero per cent feed left over. From the second day onwards the palatability of the silage treatments improved. On the second day, treatments with zero per cent left over feed were wilted water hyacinth + molasses (5%), wilted water hyacinth + cassava powder (10%), wilted water hyacinth + rice straw (10%) + cassava powder (10%), and wilted water hyacinth + guinea grass (10%) + cassava powder (10%).

The treatment with the least preference by the animals was fresh water hyacinth + rice straw (10%) + rice bran (10%). On the third day too, the least preferred silage treatment was fresh water hyacinth + rice straw (10%) + rice bran (10%). Baldwin *et al.* (1975) reported that there is positive correlation between preservative level, pH and the acceptability of silage to cattle. Woomer *et al.* (2000) reported that without additives, the pH of water hyacinth silage alone was 7.33 suggesting poor quality while addition of 15 per cent maize bran or molasses result in silage of pH 4.1 and 4.2 respectively and was readily accepted by goats and young steers.

From the results, it can be concluded that palatable silage can be made from wilted water hyacinth using additives such as molasses and cassava powder. Both molasses and cassava powder ensured the quality of silage by lowering pH and enhancing animal intake. The quality of rice bran added silages was low in terms of pH, odour and palatability; although its nutritional quality was high. Based on the quality parameters, wilted water hyacinth along with molasses (5%) or cassava flour (10%) and wilted water hyacinth along with cassava powder (10%) plus rice straw (10%) or guinea grass (10%) are the best options for utilizing water hyacinth as silage for feeding animals.

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Herbicides for weed management in dry direct-seeded rice

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ABSTRACT

A field experiment was conducted during the *Kharif* season of 2015 to 2017 for three years at Agricultural Research Station, Vadgaon Maval, Pune, Maharashtra to find out the efficacy of different weed control methods on dry direct-seeded rice and its economics. Pretilachlor 0.450 kg/ha as pre-emergence application (PE) at 2-3 days after sowing (DAS) followed by (*fb*) azimsulfuron 0.035 kg/ha as post-emergence application (PoE) at 25 DAS effectively managed weeds in dry-DSR and gave the higher grain yield (5.62 t/ha), net returns (` 82777/ha), higher B:C ratio (2.8) with lower weed index (2.78) and higher weed control efficiency (87.7%).

Rice (*Oryza sativa* L.) is a major food grain crop of the world and more than half of the population subsists on it (The Columbia Encyclopedia 2000). India is the second largest rice producing country in the world. The method of direct-seeding avoids the transplanting and puddling operations and is an attractive and sustainable alternative to traditional transplanting of rice. Dry direct-seeding of rice (dry-DSR) offers advantages such as faster and easier planting, reduced labour, earlier crop maturity by 7–10 days, more efficient water uses and higher tolerance of water deficit, less methane emission (Ladha *et al.* 2015) and often higher profit in areas with an assured water supply (Balasubramanian and Hill 2002).

A major impediment in the successful cultivation of dry-DSR in tropical countries is heavy infestation of weeds which causes rice grain yield losses that range from 50-91% (Paradkar *et al.* 1997, Rao *et al.* 2007, Chauhan and Johnson 2010, Rao and Ladha 2011) due to simultaneous emergence of weeds and crop and less availability of efficient selective herbicides for control of weeds during initial stages of crop weed competition. Hence, present study was carried out to evaluate the efficacy of different chemical and mechanical weed control methods and its economics in dry-DSR.

A field experiment was carried out during *Kharif* 2015, 2016 and 2017 for three years at Agricultural Research Station, Vadgaon Maval, Pune, Maharashtra. The experiment consisted of nine treatments comprising of unweeded check, weed free and weed control methods, *viz*. pendimethalin [1.0 kg/ha, pre-emergence application at 2-3 days after seeding (DAS)] followed by (*fb*) metsulfuron-methyl + chlorimuron-ethyl (0.004 kg/ha, post-emergence application (PoE) at 25 DAS), pretilachlor (0.450 kg/ha, PE at 2-3 DAS) *fb* metsulfuron-methyl + chlorimuron-ethyl (0.004 kg/ha, PoE at 25 DAS), oxyflourfen(0.150 kg/ha, PE at 2-3 DAS) *fb* metsulfuron-methyl + chlorimuron-ethyl (0.004 kg/ha, PoE at 25 DAS), pendimethalin (1.0 kg/ha, PE at 2-3 DAS) *fb* azimsulfuron (0.035 kg/ha, PoE at 25 DAS), pretilachlor EC (0.450 kg/ha, PE at 2-3 DAS) *fb* azimsulfuron (0.035 kg/ha, PoE at 25 DAS), oxyflourfen (0.150 kg/ha, PE at 2-3 DAS) *fb* azimsulfuron (0.035 kg/ha, PoE at 25 DAS) and hand weeding (25 and 45 DAS).

The experiment was laid out in a randomized block design with three replications. The rice variety '*Phule Samruddhi*' was sown at 22.5 cm distance during *Kharif* 2015, 2016 and 2017. The crop was raised with recommended package of practices. All the herbicides were sprayed by using water 500 l/ha with the help of sprayer fitted with flat fan nozzle. The weed samples were taken out as per treatment were oven dried for about one week and weed biomass was recorded. All the other recommended package of practices except weed control was followed to raise the direct dry seeded crop.

Effect on weeds

In the experimental plots dominant weed flora consisted of monocots as *Echinochloa colona* and *Cynodon dactylon* among grasses; *Cyperus iria* and *Cyperus defformis* among sedges while dicots like *Eclipta alba*, *Portulaca oleracea*, *Celosia argentea* and *Ludwigia parviflora* for three years.

Significantly the lowest weed bioamass and weed index with the highest weed control efficiency were recorded in the weed free treatment (**Table 1 and 2**). The second-best treatment was pretilachlor (0.450 kg/ha, PE at 2-3 DAS) *fb* azimsulfuron (0.035 kg/ha, PE at 25 DAS) having the lowest weed biomass (19.50 g/m^2) with higher weed control efficiency (87.7%) and lower weed index (2.78). The highest weed biomass was recorded in unweeded check. Similar result was close conformity of Singh *et al.* (2010).

Effect on rice

The highest mean rice grain (5.78 t/ha) and straw yield (6.52 t/ha) were observed in the weed free treatment (**Table 3**). It was at par with pretilachlor (0.450 kg/ha PE at 2-3 DAS) *fb* azimsulfuron (0.035 kg/ha, PoE at 25 DAS) with equivalent grain yield (5.62 t/ha) and straw yield (6.35 t/ha). These results are in close conformity with Abraham *et al.* (2014)

Economics

Weed free recorded significantly highest gross returns (` 133330/ha) (**Table 4**) and was at par with pretilachlor (0.450 kg/ha, PE at 2-3 DAS) *fb* azimsulfuron (0.035 kg/ha, PoE at 25 DAS) having gross returns (` 129727/ha). Significantly highest net returns (` 82777/ha) was obtained with pretilachlor

Table 1. Weed density, weed biomass, weed control efficiency and mean weed indexin dry direct-seeded rice as affected by different treatments

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				Weed control efficiency (%)				Weed index			
	2015	2016	2017	Pooled	2015	2016	2017	Pooled	2015	2016	2017	Pooled	2015	2016	2017	Pooled
Pendi. 1.0 kg/ha PE + mets. + chlor. WP 0.004 kg/ha PoE	28	33	21	27	43	50	34	42	74	71	76	73	22	25	24	24
Preti. 0.450 kg/ha PE + mets. + chlor. 0.004 kg/ha PoE	18	19	15	17	31	33	24	29	81	81	83	82	12	19	13	15
Oxyfl. 0.150 kg/ha PE + mets. + chlor. 0.004 kg/ha PoE	25	23	20	23	39	37	31	36	76	78	78	78	17	18	16	17
Pendi. 1.0 kg/ha PE + azim. 0.035 kg/ha PoE	26	25	22	24	43	40	34	39	74	77	76	76	21	19	22	21
Preti. 0.450 kg/ha PE + azim. 0.035 kg/ha PoE	14	13	12	13	21	20	17	19	87	88	88	88	4.7	1.1	2.5	2.8
Oxyf. 0.150 kg/ha PE + azim. 0.035 kg/ha PoE	21	20	19	20	35	32	27	31	79	81	81	80	14	16	16	15
Hand weeding (25 and 45 days after seeding)	33	31	25	30	57	54	45	52	65	68	68	67	27	24	27	26
Weed free	0	0	0	0	0	0	0	0	100	100	100	100	0	0	0	0
Unweeded check	99	104	86	96	163	171	143	159	0	0	0	0	74	76	75	75
LSD (p=0.05)	3.1	3.7	3.3	3.4	11.4	11.0	10.2	10.7	5.7	2.2	2.0	2.2				

Pendi = Pendimethalin; mets = Metsulfuron-methyl; chlor = Chlorimuron-ethyl; Preti = Pretilachlor ; Oxyfl = Oxyflourfen ; azim = Azimsulfuron

Table 2. Growth and yield attributes as affected by different treatments in dry direct-seeded rice

Treatment	Plant height (cm)				Number of tillers per plant			
	2015	2016	2017	Pooled	2015	2016	2017	Pooled
Pendimethalin 1.0 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl WP 0.004 kg/ha PoE	79.9	76.6	81.9	79.4	13	13	13	13
Pretilachlor 0.450 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	87.8	82.7	91.5	87.3	14	14	15	14
Oxyflourfen 0.150 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	85.3	84.1	90.8	86.7	14	15	14	14
Pendimethalin 1.0 kg/ha PE + azimsulfuron 0.035 kg /ha PoE	80.4	83.4	84.0	82.6	13	14	13	14
Pretilachlor 0.450 kg/ha PE + azimsulfuron 0.035 kg /ha PoE	91.9	90.6	91.9	91.5	18	19	19	19
Oxyflourfen 0.150 kg/ha PE + azimsulfuron 0.035 kg/ha PoE	87.7	86.3	90.9	88.3	14	14	14	14
Hand weeding (25 and 45 days after seeding)	74.5	78.0	78.3	76.9	12	12	12	12
Weed free	92.9	91.3	92.5	92.3	19	19	20	19
Unweeded check	63.2	56.2	64.7	61.3	5	4	5	5
LSD (p=0.05)	13.5	13.4	14.2	13.2	2.2	3.1	2.2	2.1

Treatment	Number of grains per panicle				Length of panicle (cm)			
	2015	2016	2017	Pooled	2015	2016	2017	Pooled
Pendimethalin 1.0 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl WP 0.004 kg/ha PoE	244	230	249	241	17.6	17.0	18.2	17.6
Pretilachlor 0.450 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	275	248	285	269	19.9	18.4	20.8	19.7
Oxyflourfen 0.150 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	260	252	276	263	18.8	18.7	20.2	19.2
Pendimethalin 1.0 kg/ha PE + azimsulfuron 0.035 kg /ha PoE	245	250	256	250	17.7	18.5	18.7	18.3
Pretilachlor 0.450 kg/ha PE + azimsulfuron 0.035 kg /ha PoE	297	306	319	307	21.5	22.6	23.3	22.5
Oxyflourfen 0.150 kg/ha PE + azimsulfuron 0.035 kg/ha PoE	268	259	277	268	19.4	19.2	20.2	19.6
Hand weeding (25 and 45 days after seeding)	227	234	238	233	16.5	17.3	17.4	17.1
Weed free	312	308	327	316	22.6	22.8	23.9	23.1
Unweeded check	81	71	83	78	11.1	10.0	11.1	10.7
LSD (p=0.05)	39.0	38.2	41.8	37.5	2.77	3.82	2.95	2.66

Table 4. Grain and straw yields as affected by different treatments in dry direct-seeded rice

Treatment	Grain yield (t/ha)				Straw yield (t/ha)			
	2015	2016	2017	Pooled	2015	2016	2017	Pooled
Pendimethalin1.0 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl WP 0.004 kg/ha PoE	4.42	4.25	4.55	4.40	4.91	4.85	5.18	4.98
Pretilachlor 0.450 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	4.99	4.59	5.19	4.92	5.55	5.22	5.92	5.56
Oxyflourfen 0.150 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	4.72	4.67	5.04	4.81	5.14	5.31	5.75	5.40
Pendimethalin 1.0 kg/ha PE + azimsulfuron 0.035 kg/ha PoE	4.45	4.63	4.66	4.58	4.94	5.26	5.31	5.17
Pretilachlor 0.450 kg/ha PE + azimsulfuron 0.035 kg/ha PoE	5.38	5.66	5.82	5.62	5.99	6.45	6.62	6.35
Oxyflourfen 0.150 kg/ha PE + azimsulfuron 0.035 kg/ha PoE	4.86	4.79	5.05	4.90	5.40	5.47	5.76	5.54
Hand weeding (25 and 45 days after seeding)	4.12	4.33	4.35	4.27	4.58	4.92	4.95	4.82
Weed free	5.67	5.70	5.97	5.78	6.29	6.49	6.79	6.52
Unweeded check	1.47	1.31	1.50	1.43	1.59	1.45	1.66	1.57
LSD (p=0.05)	0.70	0.71	0.77	0.69	0.78	0.86	0.91	0.81

Table 4. Economics of dry direct-seeded rice cultivation as affected by different treatments

Treatment	Mean gross returns ($x10^3$ `/ha)				Net Returns ($x10^3$ `/ha)				B:C ratio			
	2015	2016	2017	Pooled	2015	2016	2017	Pooled	2015	2016	2017	Pooled
Pendimethalin1.0 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl WP 0.004 kg/ha PoE	98.77	99.65	106.54	101.65	51.21	52.28	59.17	54.22	2.1	2.1	2.2	2.1
Pretilachlor 0.450 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	111.65	107.53	121.65	113.61	66.20	62.39	76.51	68.37	2.5	2.4	2.7	2.5
Oxyflourfen 0.150 kg/ha PE + metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	105.22	109.35	118.14	110.90	59.24	63.12	71.90	64.76	2.3	2.4	2.6	2.4
Pendimethalin 1.0 kg/ha PE + azimsulfuron 0.035 kg/ha PoE	99.40	108.41	109.25	105.68	51.61	58.60	59.44	56.55	2.1	2.2	2.2	2.1
Pretilachlor 0.450 kg/ha PE + azimsulfuron 0.035 kg/ha PoE	120.34	132.58	136.25	129.72	74.65	84.99	88.67	82.77	2.6	2.8	2.9	2.8
Oxyflourfen 0.150 kg/ha PE + azimsulfuron 0.035 kg/ha PoE	108.53	112.34	118.23	113.04	62.32	63.67	69.56	65.18	2.3	2.3	2.4	2.4
Hand weeding (25 and 45 days after seeding)	92.17	101.44	101.88	98.50	42.11	51.80	52.66	48.86	1.8	2.0	2.1	2.0
Weed free	126.62	133.57	139.79	133.33	73.83	80.78	85.73	80.11	2.4	2.5	2.6	2.5
Unweeded check	32.76	30.55	35.11	32.81	-10.58	-12.78	-8.22	-10.53	0.8	0.7	0.8	0.8
LSD (p=0.05)	15.81	16.83	17.99	13.01	15.81	16.83	17.99	13.01				

(0.450 kg/ha, PE at 2-3 DAS) *fb* azimsulfuron (0.035 kg/ha, PoE at 25 DAS) which was at par with the weed free treatment (` 80117/ha). The highest B:C ratio (2.8) was observed with pretilachlor (0.450 kg/ha, PE at 2-3 DAS) *fb* azimsulfuron (0.035 kg/ha, PoE at 25 DAS) (**Table 4**).

The gram was dibbled immediately after harvest of experimental rice plot to observe the effect of different treatments on succeeding crop. The herbicides applied to the rice crop did not affect the germination of the succeeding crop gram.

On the basis of this study, it can be concluded that in drilled dry-seeded rice, effective management of weeds with higher economical returns may be obtained with pre-emergence application of pretilachlor at 0.450 kg/ha at 2-3 days after sowing followed by post-emergence application of azimsulfuron at 0.035 kg/ha at 25 days after sowing.

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Effect of herbicides to control weeds in wheat

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ABSTRACT

Field experiments was conducted to study the effect of weed control methods on wheat (*Triticum aestivum* L.) during *Rabi* seasons of 2014-15 and 15-16 at Agronomy Research Farm of NDUAT, Kumarganj, Ayodhya (U.P.). Pre-emergence application of pendimethalin + metribuzin (1.0 + 0.175 kg/ha) being *at par* with weed free and pendimethalin (1.0 kg/ha) followed by sulfosulfuron (0.025 kg/ha) significantly reduced the density of weeds as compared to other treatments. Pre-emergence application of pendimethalin + metribuzin (1.0 + 0.175 kg/ha) significantly increased all growth and yield contributing characters, *viz.* plant height, dry matter accumulation, spikelength, grains/spike obtained with weed free. Among different herbicidal treatments, maximum grain and straw yields were recorded under pendimethalin + metribuzin (1.0 + 0.175 kg/ha) (4.22 and 5.70 t/ha, respectively). However, the highest benefit: cost ratio was recorded in weed free (1.97) followed by pendimethalin + metribuzin (1.0 + 0.175 kg/ha) (1.91).

Weed infestation is one of the main causes of low wheat yield not only in India but all over the world, as it reduces wheat yield by 37-50% (Waheed *et al.* 2009). Rice-wheat is one of the most important cropping systems in northern part of the country. The *Phalaris minor* is one of the very serious problems in wheat in this cropping system and sometimes almost 65% crop losses have been reported (Chhokar *et al.* 2008). Broad-leaved weeds (BLWs) are also causing a threat, but their management is comparatively easier and effective, whereas, control of *Phalaris minor* has become a serious challenge. Chemical weed control is a preferred practice due to scare and costly labour as well as lesser feasibility of mechanical or manual weeding in wheat.

Some new ready-mix herbicide, *viz*. sulfosulfuron + metsulfuron (pre-mix), mesosulfuron + iodosulfuron (pre-mix), clodinofop + metsulfuron (pre-mix) must be tested to control many of the weeds in wheat crop because some of broad-leaved weeds BLWs or grassy weeds are not control by applying single herbicide molecule in wheat. Considering this fact in view, a field experiment was conducted during *Rabi* season of 2014-15 and 2015-16 at Agronomy Research farm of N.D. University of Agriculture & Technology, Kumarganj, Ayodhya (U.P.) to study the bio-efficiency of combination of herbicides against complex weed flora and their effect on growth and yield of wheat.

The Field Experiment was conducted during *Rabi* season in 2014-15 and 2015-16 at Agronomy Research Farm, N.D. University of Agriculture & Technology, Kumarganj, Ayodhya. The experimental site was situated in main campus of the university, about 42 km. away from Ayodhya on Raibareli road at $26^0 47'$ N latitude, $82^0 12'$ E longitude and an altitude of 113 meters above mean sea level in North Indo-gangatic plain. The soil of the experimental field was silt loam with medium fertility status (Available Nitrogen – 180, phosphorus -18 and potassium- 260 Kg/ha). The crop was fertilizered with 120 kg N, 60 kg P_2O_5 and 30 kg K_2O/ha. The experiment was laid out in a randomized block design (RBD) with three replications, comprising 12 treatments allocated randomly. Pre-emergence pendimethalin 0.75 kg/ha and 1.0 kg/ha were applied on 3rd day of sowing and post-emergence sulfosulfuron 0.025 kg/ha, clodinafop 0.06kg/ha and sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha were applied at 30days after sowing (DAS) of crop. Variety (*PBW-502*) of wheat was sown on 9 December 2014-15 and 2015-16. Herbicides were sprayed with the help of manually operated knapsack sprayer fitted with fan nozzle using 600 litres water per hectare. Data on weed density was taken with quadrate measuring 0.5×0.5m placed randomly at four spot to each plot at 60 DAS and harvest stage and weed control efficiency was calculated based on total biomass of weed. The weed data were subjected to square root transformation to normalize the distribution. The data on yield and yield attributes of wheat were recorded at the time of crop harvest.

The herbicidal treatments reduced the weed density significantly over un-weeded control (**Table 1**). Next to weed free, pre-emergence application of pendimethalin + metribuzin 1.0 + 0.175 kg/ha was found most effective to control the weeds as compared to other herbicides. Pre-emergence application of pendimethalin followed by *(fb)* sulfosulfuron (1.0*fb* 0.025 kg/ha) was most effective to control the weeds followed by post-emergence application of sulfosulfuron + metsulfuron 0.03 + 0.002 kg/ha and both were significantly superior to weedy check. The results were in accordance with Nayak *et al.* (2003).

The spectrum of weeds has a bearing on the efficiency of the management practices adopted. Pre-emergence application of pendimethalin + metribuzin 1.0 + 0.175 kg/ha provided the highest weed control efficiency (93.3%) followed by pre-emergence application of pendimethalin followed by sulfosulfuron (1.0 *fb* 0.025 kg/ha, 92.23%). This was mainly due to the lowest weed dry weight under the effects of above treatment. Nayak *et al.* (2003) and Chhipa *et al.* (2005) have also reported increase in weed control efficiency with use of herbicides in wheat.

Weed index is the measure of reduction in yield caused by weed infestation and directly related with weed density and weed dry matter. Pre-emergence application of pendimethalin + metribuzin 1.0 + 0.175 kg/ha recorded the lowest weed index of 5.12 followed by pre-emergence application of pendimethalin *fb* sulfosulfuron (1.0 *fb* 0.025 kg/ha) of 6.99 as compared to weed index of 32.50 with weedy check. This was mainly due to lesser crop weed competition in herbicidal treatment as compared to weedy check within term resulted higher yield vis-à-vis reduce weed index. The results are in agreement with Chhipa *et al.* (2005).

Effect on crop

Different weed control treatments increased the plant height and dry matter accumulation significantly at harvest stage. Tallest plants (92.2 cm) were recorded under weed free which was at par with pre-emergence application of pendimethalin + metribuzin (1.0 + 0.175 kg/ha) and pre- emergence of pendimethalin *fb* sulfosulfuron (1.0 *fb* 0.025 kg/ha) over all rest of the treatment with weedy check plot (**Table 1**). The increase in plant height was due to greater availability of nutrient, which resulted profuse growth of plants at various growth factors. Similar results have also been reported by Satao and Padola (1994). Similar trend was also found in plant dry matter accumulation.

Spike length and no. of grains/spike increased significantly with weed control treatments. The largest spikes length of 8.96 cm was recorded with weed free which was at par with pendimethalin + metribuzin (1.0 + 0.175 kg/ha), pendimethalin *fb* sulfosulfuron (1.0 *fb* 0.025 kg/ha) and sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha). Amongst different herbicidal treatments, clodinafop 0.06 kg/ha recorded the lowest length of spike (6.94 cm).

The number of grains/spike was found significantly more under all the weed control treatments as compareded to weedy check. Weed

Table 1.Effect of herbicides on weed density and growth parameters at different growth stages (pooled data of two years)

Treatment	Weed density (no./ m^2)		W.C.E. (%)	W.I. %	Plant height at harvest (cm)	Dry matter accumulation (g/m^2) at harvest
	60 DAS	At harvest				
Pendimethalin (0.75 kg/ha)	(92.4)9.67	(51.3)7.23	76.70	25.75	80.5	248
Sulfosulfuron (0.025 kg/ha)	(92.4)9.66	(34.0)5.91	79.32	22.38	82.2	253
Metribuzin (0.21 kg/ha)	(111.7)10.66	(40.7)6.46	78.05	25.39	81.4	251
Clodinafop (0.06 kg/ha)	(97.7)9.93	(46.1)6.86	74.27	26.07	80.4	242
Pendimethalin + metribuzin (1.0 + 0.175 kg/ha)	(50.3)7.16	(19.9)4.57	93.33	5.12	92.2	270
Pendimethalin*fb*sulfosulfuron (1.0 + 0.025 kg/ha)	(56.9)7.61	(22.9)4.88	92.23	6.99	91.2	266
Sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha)	(65.3)8.14	(25.2)5.12	91.30	11.13	89.4	264
Pinoxaden + metsulfuron (0.06 + 0.004 kg/ha)	(76.7)8.82	(29.3)5.50	89.97	14.06	87.8	262
Mesoulfuron + iodosulfuron (0.012 + 0.0024 kg/ha)	(81.7)9.09	(31.5)5.70	88.77	15.07	86.9	259
Clodinafop + metsulfuron(0.06 + 0.004 kg/ha)	(82.3)9.13	(33.4)5.86	88.15	15.56	85.8	258
Weed free	(0)1.00	(0)1.00	100	0	93.2	272
Un-weeded control	(199.4)14.15	(70.2)8.44	0	32.50	77.7	239
LSD (p=0.05)	5.70	4.64	-		2.6	5

*Values in parentheses are original. **Values transformed by ($\sqrt{x+1}$); WCE: weed control efficiency, WI: weed index

Table 2. Effect of weed control treatments on length of spike, grains/spike and test weight (pool data of two years)

Treatment	Spike length (cm)	No. of grains/spike	Grain yield t/ha	Straw yield t/ha	B:C Ratio
Pendimethalin (0.75 kg/ha)	7.11	34.22	3.30	4.73	1.39
Sulfosulfuron (0.025 kg/ha)	7.25	34.66	3.45	4.92	1.53
Metribuzin (0.21 kg/ha)	7.22	34.40	3.32	4.74	1.45
Clodinafop (0.06 kg/ha)	6.94	33.11	3.29	4.70	1.38
Pendimethalin + metribuzin (1.0 + 0.175 kg/ha)	8.91	40.25	4.22	5.70	1.91
Pendimethalinfbsulfosulfuron (1.0 + 0.025 kg/ha*)*	8.83	39.11	4.13	5.64	1.89
Sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha)	8.63	36.55	3.95	5.50	1.82
Pinoxaden + metsulfuron (0.06 + 0.004 kg/ha)	8.19	36.33	3.82	5.41	1.74
Mesoulfuron + iodosulfuron (0.012 + 0.0024 kg/ha)	7.64	35.55	3.77	5.35	1.68
Clodinafop + metsulfuron(0.06 + 0.004 kg/ha)	7.86	35.11	3.75	5.33	1.66
Weed free	8.96	40.61	4.44	6.00	1.97
Un-weeded control	6.91	30.00	3.00	4.30	1.28
LSD (p=0.05)	2.00	1.92	0.34	0.47	-

free produced the highest number of 40.6 grains/spike being at par with pendimethalin + metribuzin at 1.0 + 0.175 kg/ha, pendimethalin *fb* sulfosulfuron at 1.0 + 0.025 kg/ha (40.25 and 39.11, respectively) but significantly superior to the rest of treatments. The lowest grains/spike (30.00) was recorded in weedy check.

The weed control treatments resulted significant increase in grain yield as compare to weedy check (3.0 t/ha). The maximum grain yield of 4.4 t/ha was recorded under weed free plots which remained at par with pre-emergence application of pendimethalin + metribuzin at 1.0 + 0.175 kg/ha (4.22 t/ha) and pre-emergence application of pendimethalin *fb* sulfosulfuron at 1.0 *fb* 0.025 kg/ha (4.13t/ha) (**Table 2**). This Exhibed an increase of grain yield (40.6%) over pre-emergence application of pendimethalin + metribuzin at 1.0 + 0.175 kg/ha and un-weeded control.

It was clearly found that in weed free and sulfosulfuron + metsulfuron at 0.03 + 0.002 kg/ha resulted into significant increase in straw yield as compared to weedy check. The maximum straw yield of 6 t/ha was recorded in weed free followed by pendimethalin + metribuzin at 1.0 + 0.175 kg/ha (5.70 t/ha) and pendimethalin *fb* sulfosulfuron at 1.0 *fb* 0.025 kg/ha (5.64 t/ha) exhibiting an increase of (26.3%) over clodinafop + metsulfuron at 0.06 + 0.004 (4.30 t/ha).

Weed free as well as pendimethalin + metribuzin at 1.0 + 0.175 kg/ha, pendimethalin *fb* sulfosulfuron at 1.0 *fb* 0.025 kg/ha and sulfosulfuron + metsulfuron at 0.03 + 0.002 kg/ha treatment also recorded highest benefit cost ratio of 1.91, 1.89 and 1.82 as compared to weedy check of 1.28, due to higher grain and straw yield to greater extent as compared to lesser increase in cost of cultivation with these treatments. The results are in agreement with Kushwaha and Singh (2000).

It was concluded that pre -emergence application of pendimethalin + metribuzin at 1.0 + 0.175 kg/ha was found most effective in controlling weeds. Pre- emergence application of pendimethalin followed by sulfosulfuron (1.0 *fb* 0.025kg/ha) was equally effective.

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Promising post-emergence herbicides for effective management of broad-leaved weeds in soybean

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ABSTRACT

A field experiment was conducted during rainy (*Kharif*) seasons of 2013 and 2014 at Agriculture Research Station, Mahatma Phule Agricultural University, Kasbe Digraj, Sangli, Maharashtra. Significant weed density reduction was recorded with fluthiacet-methyl at increased application rates of 5 g/ha to 15 g/ha. Fluthiacet-methyl 15 g/ha + 0.25% NIS controlled broad-leaved weeds effectively. Biomass and total broad-leaved weed density were the lowest with fluthiacet-methyl 15 g/ha + 0.25% NIS. Weed control efficiency was higher (80.86%) with fluthiacet-methyl 15 g/ha + 0.25% NIS. Seed yield was the highest (1.91 and 1.93 t/ha during 2013 and 2014, respectively) in weed free plot followed by fluthiacet-methyl 15 g/ha + 0.25% NIS applied as post-emergence (2-5 leaf stage of weeds) with the highest B:C ratio.

Soybean (*Glycine max* L.) is mostly grown for oil (20%) and protein (40%) around the world. Weeds are the major biotic factor responsible for poor soybean yield. Malik *et al.* (2006) have reported 55% soybean yield reduction with broad-leaved weeds (80%), grasses and sedges (20%) infestation throughout the crop season. Major broad-leaved weeds of soybean are *Celosia argentia*, *Digera arvensis*, *Commelina benghalensis*, and *Amaranthus viridis* (Pratap Singh and Rajkumar 2008). Soybean yield can be enhanced by almost 50% by adopting timely weeding (Tewari *et al.* 1991). Farmers are mostly using pre-plant incorporated or pre-emergence herbicides for weed control in soybean, but their efficacy is reduced due to variation in climatic and edaphic factors (Mahendra Singh *et al.* 2013). Hence, there is a need to explore the possibility of post-emergence herbicides for effective control of weeds in soybean. Therefore, an experiment was conducted to assess the efficacy of fluthiacet-methyl in managing the broad-leaved weeds in soybean.

A field experiment was conducted at Agriculture Research Station (ARS), Mahatma Phule Agricultural University, Kasbe Digraj, Sangli, Maharashtra, India during *Kharif* seasons of 2013 and 2014. Average rainfall of station is 692.4 mm in 49 rainy days. The experiment was laid out in medium black deep soil (0-45 cm depth) which is low in available nitrogen (167 kg/ha) and phosphorus (11.50 kg/ha) content, and high in available potash content (632 kg/ha) with pH 8.27. Twelve treatments, *viz*. control, fluthiacet-methyl (10.3% EC) 7.5, 10.0, 12.8 and 15 g/ha, fluthiacet-methyl + 0.25% NIS EC 7.5, 10.0, 12.8 and 15 g/ha, imazethapyr (10% SL) 100 g/ha, chlorimuron (25% WP) 9 g/ha, weed free and untreated check (UTC) were replicated thrice in a randomized block design. The gross and net plot size of the experiment were 5 x 3.6 m and 4.5 x 2.7 m, respectively. Soybean seed (75 kg/ha) of variety *'KDS-344'* was sown on 15 July, 2013 and 10 July, 2014 at 45 x 5 cm spacing. Crop was applied with recommended dose of fertilizer *i.e.* 75:50:0 N: P_2O_5:K_2O kg/ha. All the herbicides were sprayed with knapsack sprayer fitted with flat-fan nozzle using 500 litres of water per hectare.

Data on weeds (weed density, weed biomass) were subjected to square root transformation. Crop was harvested on 6 November, 2013 and 1 November, 2014. All the herbicides were applied as post-emergence at 2-5 leaf stage of weed. Data on species wise weed density at pre-spray (before herbicide application) and 30 DAA of fluthiacet-methyl was recorded. Individual broad-leaved weeds were recorded using a quadrant of 1 × 1m from three random spots per plot and the average was reported as weed density (no./m^2). The total broad-leaved weeds were oven dried and weed dry matter was recorded at 30 DAA and expressed as biomass (g/m^2). Data of both weed density and biomass was analyzed statistically using suitable square root transformation. Weed control efficiency (WCE) was calculated for total broad-leaved weeds using the weed biomass with the following formula.

$$\text{WCE} = \frac{\text{Weed biomass in UTC} - \text{Weed biomass of weeds in treatments}}{\text{Biomass of weeds in UTC}}$$

The crop was harvested at physiological maturity. After the harvest, threshing was done and seed yield of each treatment was recorded and expressed as t/ha. The yield attributes, *viz.* number of pods/plants; number of seeds/pod and 100 seed weight (g) were recorded. Gross returns, net returns as well as B:C ratio were worked out using prevailing prices of inputs and outputs.

Effect on weeds

Major broad-leaved weed species in soybean field before spraying were *Acalypha indica* (24.37% during 2013 and 19.18% during 2014), *Digera arvensis* (21.52% during 2013 and 16.48% during 2014), *Commelina benghalensis* (17.45% during 2013 and 21.15% during 2014), *Amaranthus viridis* (19.13% during 2013 and 20.96% during 2014), and other species include *Parthenium hysterophorus, Trianthema portulacastrum* and *Portulaca oleracea* (18.49% during 2013 and 21.27% during 2014) (**Table 1**). Total broad-leaved weed species were controlled effectively by fluthiacet-methyl 15 g/ha + 0.25% NIS (applied at 2-5 leaf stage of weeds) resulting in significantly reduced weed density as reported by Hayes (2008). Number of broad-leaved weed species, at 30 days after application, was higher (56.64 no./m^2) in weedy check and lowest with fluthiacet-methyl 15 g/ha + 0.25% NIS (4.68 no./m^2). Among the broad-leaved weed species, weed density at 30 days after application was highest for *Acalypha indica* (13.02 no./m^2), *Digera arvensis* (12.06 no./m^2), *Commelina benghalensis* (11.98 no./m^2) and *Amaranthus viridis* (10.66 no./m^2) in untreated plot.

The species *Acalypha indica, Commelina benghalensis* were controlled effectively by fluthiacet-methyl 15 g/ha + 0.25% NIS, which has recorded significantly lower weed density than rest of the treatments except fluthiacet-methyl 12.8 g/ha + 0.25% NIS and fluthiacet-methyl 15 g/ha. Effective control with significantly lower weed density of *D.*

Table 1. Broad-leaved weed density, weed biomass and weed control efficiency as influenced by fluthiacet-methyl in soybean (average of two years)

Treatment	Broad-leaved weed density before spraying (no./m^2)						Broad-leaved weed density at 30 DAA (no./m^2)						Weed Biomass at 30 DAA (g/m^2)	WCE (%)
	CB	AI	DA	AV	Others	Total	CB	AI	DA	AV	Others	Total		
Fluthiacet-methyl 7.5 g/ha	2.9 (7.67)	3.0 (8.03)	2.8 (6.89)	2.9 (7.42)	2.6 (5.88)	6.1 (35.9)	2.2 (3.98)	2.2 (3.82)	2.5 (5.45)	2.2 (3.95)	2.1 (3.34)	4.6 (20.5)	7.3 (52.3)	51.67
Fluthiacet-methyl 10 g/ha	2.9 (7.49)	3.0 (7.99)	2.9 (7.56)	2.8 (6.96)	2.8 (6.67)	6.1 (36.7)	2.1 (3.45)	2.2 (3.89)	2.3 (4.08)	2.0 (3.12)	1.9 (2.68)	4.3 (17.2)	7.1 (49.7)	53.79
Fluthiacet-methyl 12.8 g/ha	2.6 (5.98)	2.9 (7.52)	2.7 (6.35)	2.9 (7.55)	2.8 (7.12)	5.9 (34.5)	2.0 (3.02)	2.0 (2.92)	2.0 (2.89)	1.9 (2.56)	1.8 (2.18)	3.8 (13.6)	5.5 (29.0)	67.47
Fluthiacet-methyl 15 g/ha	2.9 (7.36)	2.9 (7.45)	2.8 (6.98)	2.8 (6.84)	2.7 (6.13)	6.0 (34.8)	1.1 (0.24)	1.4 (0.89)	1.6 (1.60)	1.8 (2.12)	1.6 (1.56)	2.7 (6.39)	4.3 (17.9)	74.35
Fluthiacet-methyl 7.5 g/ha + 0.25% NIS	3.0 (7.82)	3.1 (8.32)	2.8 (6.72)	3.0 (7.96)	3.0 (8.30)	6.3 (39.1)	2.4 (4.78)	2.3 (4.26)	2.3 (4.20)	2.3 (4.45)	1.9 (2.52)	4.6 (20.2)	7.0 (47.8)	55.87
Fluthiacet-methyl 10 g/ha + 0.25% NIS	2.6 (5.78)	2.9 (7.67)	2.9 (7.67)	2.8 (7.05)	2.9 (7.28)	6.0 (35.4)	2.0 (3.04)	2.1 (3.34)	2.1 (3.22)	1.9 (2.75)	1.6 (1.58)	3.9 (13.9)	5.5 (29.5)	67.02
Fluthiacet-methyl 12.8 g/ha + 0.25% NIS	2.7 (6.24)	3.0 (8.24)	2.8 (6.82)	2.9 (7.68)	3.0 (7.84)	6.14 (36.8)	1.2 (0.32)	1.4 (0.95)	1.4 (1.06)	1.7 (1.78)	1.5 (1.36)	2.5 (5.47)	4.3 (17.2)	74.92
Fluthiacet-methyl 15 g/ha + 0.25% NIS	2.6 (6.02)	3.0 (7.92)	2.8 (6.94)	2.9 (7.44)	3.1 (8.92)	6.2 (37.2)	1.1 (0.18)	1.4 (0.89)	1.3 (0.79)	1.7 (1.86)	1.4 (0.96)	2.4 (4.68)	3.8 (13.2)	80.86
Imazethapyr 100 g/ha	2.7 (6.42)	2.8 (7.04)	2.5 (5.42)	2.5 (5.36)	2.6 (5.62)	5.5 (29.9)	2.0 (3.08)	2.1 (3.44)	2.2 (3.72)	2.2 (3.67)	1.8 (2.15)	4.1 (16.1)	5.4 (28.4)	69.56
Chlorimuron ethyl 9 g/ha	2.7 (6.05)	2.7 (6.08)	2.5 (5.18)	2.5 (5.32)	2.5 (5.04)	5.3 (27.7)	2.2 (3.64)	2.2 (3.88)	2.1 (3.58)	2.1 (3.48)	1.8 (2.39)	4.2 (17.0)	6.1 (36.3)	61.91
Weed free	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	100.00
Untreated	2.9 (7.67)	3.0 (7.95)	2.8 (6.96)	3.0 (7.82)	3.0 (7.96)	6.2 (38.4)	3.6 (12.0)	3.7 (13.0)	3.6 (12.1)	3.4 (10.7)	2.6 (8.92)	7.36 (56.6)	11.0 (120.7)	0
LSD (p=0.05)							0.21	0.20	0.20	0.18	0.14	0.44	0.7	

Others include broad-leaved weed species *viz.,Parthenium hysterophorus, Trianthema portulacastrum* and *Portulaca oleracea*. CB – *Commelina benghalensis;* AI – *Acalypha indica;* DA – *Digera arvensis*; AV – *Amaranthus viridis*

Data in parentheses are original weed density values; Data was subjected to square root transformation

NIS: Non-ionic surfactant adjuvant; DAA: Days after application

Table 2. Yield attributes and economics of soybean as influenced by various treatments

Treatment	No. of pods/plant		No. of seeds/pod		100 seed weight (g)		Seed yield (t/ha)		Gross returns (x10^3 `/ha)		B:C ratio	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Fluthiacet-methyl 7.5 g/ha	23.3	25.0	3.44	3.48	10.4	11.5	0.91	0.93	27.60	29.15	1.26	1.31
Fluthiacet-methyl 10 g/ha	25.0	25.7	3.44	3.46	10.5	11.1	0.92	0.94	27.90	29.46	1.27	1.33
Fluthiacet-methyl 12.8 g/ha	29.8	31.7	3.50	3.54	10.5	11.0	1.22	1.28	37.00	40.11	1.69	1.81
Fluthiacet-methyl 15 g/ha	40.0	41.1	3.37	3.39	10.7	11.0	1.53	1.63	46.40	51.08	2.11	2.30
Fluthiacet-methyl 7.5 g/ha + 0.25% NIS	26.0	27.5	3.53	3.55	11.0	10.8	0.93	0.97	28.21	30.40	1.28	1.37
Fluthiacet-methyl 10 g/ha + 0.25% NIS	33.0	33.3	3.29	3.27	10.8	10.9	1.19	1.27	36.09	39.80	1.64	1.79
Fluthiacet-methyl 12.8 g/ha + 0.25% NIS	41.0	43.0	3.31	3.33	11.1	10.4	1.65	1.66	50.35	51.40	2.28	2.31
Fluthiacet-methyl 15 g/ha + 0.25% NIS	41.8	43.7	3.43	3.45	10.9	10.8	1.67	1.71	50.65	53.59	2.30	2.40
Imazethapyr 100 g/ha	34.4	35.0	3.53	3.51	10.9	11.0	1.35	1.33	40.95	41.68	1.85	1.87
Chlorimuron ethyl 9 g/ha	31.2	31.8	3.47	3.49	10.7	11.0	1.21	1.23	36.70	38.55	1.66	1.73
Weed free	43.2	45.5	3.46	3.44	10.8	10.9	1.91	1.93	57.93	60.48	2.08	2.10
Untreated	19.0	19.7	3.51	3.53	10.8	10.9	0.72	0.74	21.84	23.19	1.03	1.05
LSD (p=0.05)	2.7	2.7	NS	NS	NS	NS	0.26	0.28				

arvensis, P. hysterophorus, T. portulacastrum and *P. oleracea* was recorded with fluthiacet-methyl 15 g/ha + 0.25% NIS. *Amaranthus viridis* was controlled effectively recording reduced weed density with fluthiacet-methyl 12.8 g/ha + 0.25% NIS compared to rest of the treatments except fluthiacet-methyl 15 g/ha + 0.25% NIS.

Biomass of broad-leaved weeds was reduced with increase in rate of application of fluthiacet-methyl from 7.5 to 15 g/ha. Lowest weed biomass was recorded in fluthiacet-methyl 15 g/ha + 0.25% NIS (13.20 g/m^2). Weed control efficiency was higher (80.86%) in treatment fluthiacet-methyl 15 g/ha + 0.25% NIS.

Yield attributes and economics

The highest seed yield (1.91 and 1.93 t/ha during 2013 and 2014, respectively) was recorded in weed free plot which was significantly higher over rest of the treatments and was at par with fluthiacet-methyl 15 g/ha + 0.25% NIS and fluthiacet-methyl 12.8 g/ha + 0.25% NIS. The lowest seed yield was recorded in untreated plot (**Table 2**). The seed yield of soybean was increased with increased rate of application of fluthiacet-methyl from 7.5 g/ha to 15 g/ha. Number of pods/plant was highest (43.25 and 45.50 during 2013 and 2014, respectively) in weed free plot and found significantly higher over rest of the treatments and was on-par with fluthiacet-methyl 15 g/ha + 0.25% NIS and fluthiacet-methyl 12.8 g/ha + 0.25% NIS. Number of pods/plant was increased as the rate of application of fluthiacet-methyl was increased from 7.5 g/ha to 15 g/ha. The lowest pods/plant was recorded in untreated plot. No. of seeds/pod and 100 seed weight (g) were not significantly different among treatments.

Maximum gross returns was realized under the weed free treatment and it was followed by fluthiacet-methyl 15 g/ha + 0.25% NIS. However, among the different herbicide treatments, fluthiacet-methyl 15 g/ha + 0.25% NIS recorded the highest B:C ratio (2.30 and 2.40 during 2013 and 2014, respectively) followed by fluthiacet-methyl 12.8 g/ha + 0.25% NIS.

It may be concluded that fluthiacet-methyl 15 g/ha + 0.25% NIS controls annual broad-leaved weeds effectively in soybean when applied as an early post-emergence (2-5 leaf stage of weeds) with higher yield and monetary returns.

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Integrated weed management in soybean

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ABSTRACT

A field experiment was conducted during 2010 to 2012 for three years at Agricultural Research Station, Karad Maharashtra to find out the suitable integrated weed management method in soybean. Post-emergence application of quizalofop-ethyl at 0.05 kg/ha + chlorimuron-ethyl at 0.009 kg/ha at 15 days after seeding (DAS) + hand weeding at 30 DAS, recorded lowest weed biomass (38.1 g/m^2) with higher weed control efficiency (62%) and lower weed index (8.0). The some treatment also recorded the highest seed yield and net returns with lower weed index (8.0) in soybean.

Soybean (*Glycine max.*) is an important rainy season crop having national productivity of 1.006 t/ha (Anonymous 2010). The sowing window for soybean in rainy season is very short and farmers give first priority to sow the crop. The weeds emerges simultaneously with the crop plants and compete with soybean causing loss in yield (35-55%) depending upon the weed flora and density (Chandel and Saxena 1998, Kewat *et al.* 2000, Singh 2007). Due to intermittent rainfall during rainy season and scanty labour, manual weeding at right stage is difficult and time consuming and expensive, so farmers rarely adopt this practices for weed control (Nainwal *et al.* 2010). Under such a situation herbicidal use with suitable dose remains the pertinent choice for controlling weeds. Herbicides in isolation, however are unable to provide complete weed control because of their selective kill (Anonymous 2010). Their use can be made more effective if supplemented with hand weeding or hoeing (Nainwal *et al.* 2010). A judicious combination of chemical and cultural methods of weed control would not only reduce the expenditure on herbicides but would benefit the crop timely by providing proper aeration and conservation of moisture (Velu and Shankaran 1996, Prakash *et al.* 1991). Thus the present experiment was conducted with an objective to identify a judicious combination of chemical and cultural weed control methods for effectively managing weeds in soybean.

A field experiment was conducted during *Kharif* season of 2010, 2011 and 2012 at Agricultural Research Station, Karad Maharashtra to identify the suitable integrated weed management method for managing weeds in soybean. The experiment was laid out in a randomized block design with ten treatments replicated thrice. Experimental treatments comprised of weedy check, weed free check, hoeing at 15 days after seeding (DAS) and 30 DAS, hoeing at 15 DAS and hand weeding at 30 DAS, imazethapyr (pursuit) 0.075 kg/ha as post- emergence (PoE) at 15 DAS, imazethapyr 0.075 kg/ha as PoE at 15 DAS and hand weeding at 30 DAS, pendimethalin 1.0 kg/ha as pre-emergence, pendimethalin 1.0 kg/ha as pre-emergence and hand weeding at 30 DAS, quizalofop-ethyl (turga super) 0.05 kg/ha + chlorimuron-ethyl (cloben) 0.009 kg/ha as PoE at 15 DAS, and quizalofop-ethyl 0.05 kg/ha + chlorimuron-ethyl 0.009 kg/ha as PoE at 15 DAS + hand weeding at 30 DAS. The experimental plot size was 6.00 x 4.20 m^2. The soybean was sown by dibbling at 30 x 10 cm spacing during *Kharif* 2010-2012. The soil of the experimental field was medium deep, with low in available nitrogen (260 kg/ha) medium in available phosphorus (45.2 kg/ha) and rich in available potash (350 kg/ha). The soil was normal in reaction with pH 6.7. Weed biomass was recorded by weighing the weeds collected from the treatment plots after drying collected weeds for about one week. Weed control efficiency was estimated on the basis of reduction in weed biomass in comparison with unweeded control and expressed as an index taking weed free as 100% efficiency. Weed index refers to reduction in soybean yield due to presences of weeds in comparison to the weed free treatment plot soybean yield. The economics of treatment was computed with prevailing market prices of products.

Table 1. Mean pooled soybean plant height, pods per plant, associated weed biomassgrain and straw yield, weed control efficiency, weed index and economics as influenced by different treatments

Treatment	Plant height (cm)	No. of pods/ plant	Weed biomass (g/m^2)	Soybean yield (t/ha)		Weed control efficiency (%)	Weed index (%)	Gross monetary returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	B:C ratio
				Grain	Straw					
Hoeing at 15 DAS and 30 DAS	64	24	66.6	2.54	1.92	36	32	46.43	27.12	2.40
Hoeing at 15 DAS and HW at 30 DAS	69	24	44.8	2.89	2.16	55	23	52.94	31.90	2.52
Imazethapyr 0.075 kg/ha as PoE at 15 DAS	59	19	72.6	2.35	1.70	31	37	42.98	22.87	2.14
Imazethapyr 0.075 kg/ha as PoE at 15 DAS and HW at 30 DAS	70	22	45.7	3.07	2.22	54	18	56.25	34.28	2.56
Pendimethalin 1.0 kg/ha as PE	60	22	72.7	2.34	1.74	30	37	42.85	23.29	2.19
Pendimethalin 1.0 kg/ha as PE and HW at 30 DAS	52	25	61.3	2.70	2.07	47	28	49.36	27.94	2.30
Quizalofop-ethyl 0.05 kg/ha + chlorimuron-ethyl 0.009 kg/ha as PoE at 15 DAS	65	26	65.5	2.45	1.73	38	34	44.91	25.21	2.28
Quizalofop-ethyl 0.05 kg/ha + chlorimuron-ethyl 0.009 kg/ha as PoE at 15 DAS + HW at 30 DAS	71	28	38.1	3.42	2.44	62	8	62.62	41.06	2.90
Weedy check	63	18	104.7	1.90	1.61	0	49	34.74	18.34	2.12
Weed free check	75	29	0	3.73	2.59	100	0	68.26	45.85	3.05
LSD (p=0.05)	8	5	13.4	0.32	0.18	5	8	5.81	5.81	-

Effect on weeds

The dominant weeds occurred in the experimental field during the three years were *Cynodon dactylon, Cyprus rotundus, Celosia argentea, Portulaca oleracea, Eclipta alba, Echinochlola colona, Alternenthra* spp., *Eupherbia* spp.*etc*.

Significantly the lowest weed biomass, higher weed control efficiency and lower weed index were recorded with weed free treatment (**Table 1**). The second best treatment was quizalofop-ethyl 0.05 kg/ ha + chlorimuron-ethyl 0.009 kg/ha PoE at 15 DAS + hand weeding at 30 DAS, which recorded the lowest weed biomass (38.1 g/m^2) with higher weed control efficiency (62%) and lower weed index (8.0). The highest weed biomass was recorded with weedy check treatment. These result are corroborates with those of Dubey *et al.* (1996).

Effect on crop

Significantly the highest plant height (75 cm), number of pods per plant (29), grain yield (3.73 t/ha) and straw yield (2.59 t/ha) were obtained in weed free treatment (**Table 1**). It was at par with quizalofop-ethyl 0.05 kg/ha + chlorimuron-ethyl 0.009 kg/ha PoE at 15 DAS + HW at 30 DAS with the next highest grain yield (3.42 t/ha) and straw yield (2.44 t/ha). The increase in soybean seed yield with integrated methods can be attributed to the fact that the crop was kept free of competition at the early critical stages of growth resulting in the crop using the land and climatic resources more efficiently (Natrajan *et al.* 1997).

Economics

Weed free treatment recorded significantly the highest gross monetary returns (` 68,269/ha) and net returns (` 45,857/ha) (**Table 1**), which was at par with quizalofop-ethyl 0.05 kg/ha + chlorimuron-ethyl 0.009 kg/ha PoE at 15 DAS + HW at 30 DAS. The benefit:cost ratio also followed similar trend. These results are in close conformity with the findings of Chandel *et al.* (1995). On the basis of study it was concluded that quizalofop-ethyl 0.05 kg/ha + chlorimuron-ethyl 0.009 kg/ha as PoE at 15 DAS + HW at 30 DAS was the best effective and economic integrated weed management treatment for soybean.

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Spacing and weed management influence on productivity and economics of sunflower

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ABSTRACT

Field experiment on economics and productivity of sunflower with response to spacing and weed management practices was conducted at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, during rainy season of (*Kharif*) 2016 and 2017 with objective of checking the suitability of spacing for moment of power weeder. Experiment was laid out in strip plot design and replicated thrice. The treatment comprised of five horizontal factors as plant spacing and five vertical factors as weed management practices. The higher cost of cultivation was registered with spacing 90 × 15 cm among different spacing and increased in gross returns, net returns, B:C ratio, per day return and seed yield with the spacing 75 × 25 cm. Hand weeding twice at 15 and 30 DAS recorded the higher cost of cultivation, gross returns, per day returns and seed yield among the different weed management practices during the both years of experimentation. Results of two year experimentation revealed that increased in net returns with pendimethalin at 1 kg/ha followed by hand weeding at 30 DAS and higher B:C ratio was recorded with pendimethalin at 1 kg/ha followed by weeder at 30 DAS.

Sunflower being a wide spaced crop and slow growth during the initial stage of the crop, provides enough room for weeds to establish and take advantage of slower initial growth of the crop. Reduction in sunflower yield upto 64% due to uncontrolled growth of weeds which in turn cause enormous loss of nutrients has been reported (Legha *et al.* 1992). Row spacing plays an important role in determining yield and yield components. To sustain the productivity in sunflower, it is prime need to practice high density planting systems, with narrow and ultra narrow spacing which will cover the soil canopy as early as possible compared to the conventional row widths. It helps in shading out weeds and reduces their competition with the crop and permit to operate the mechanical weeder in the rows due to the change in the row spacing.

A field experiment was carried out during rainy season *(Kharif)* season of 2016 and 2017 to the study the response of spacing and weed management practices on economic and productivity of sunflower at Tamil Nadu Agricultural University, Coimbatore. The experiment was laid out with strip plot design and replicated thrice. The treatment comprised of five horizontal factors as plant spacing, *viz.* S_1 (60 × 30 cm), S_2 (75 × 25 cm), S_3 (75 × 20 cm), S_4 (90 × 20 cm) and S_5 (90 × 15 cm). Five vertical factors as weed management practices like W_1 (pre-emergence herbicide pendimethalin at 1.0 kg/ha followed by hand weeding at 30 DAS), W_2 (pendimethalin at 1.0 kg/ha followed by weeder at 30 DAS), W_3 (weeding with weeder at 15 DAS and 30 DAS), W_4 (two hand weedings at 15 DAS and 30 DAS) and W_5 (weedy check). The soil of the experimental field was sandy clay loam in texture. The sunflower hybrid, TNAU Sunflower Hybrid CO2 was used as test crop. Weed management treatment were imposed as par the schedule. The recommended fertilizer dose followed for sunflower was 60:90:60 kg NPK/ha. Half dose of N and K and full dose of P were applied basally to all the treatments. The remaining N and K were top dressed at 30 DAS. The crop was harvested at maturity stage, seed yield per net plot of each treatment was recorded. Analytical data of yield sample and the computed data were subjected to statistical scrutiny as per the procedures given by Gomez and Gomez (1984). The treatment differences were worked out at five per cent probability level.

Effect on productivity

Amongst spacing combinations 75 × 25 cm, recorded maximum seed yield compared to the other spacing treatments during two years of experimention (**Table 1**). Significant increase in the seed yield with spacing 75 × 25 cm due to low damage by the power weeder moment and row spacing of 75 cm was favourable for obtaining higher seed yield which contributed to maximum number of seeds per unit area. Similar finding were obtained by Ion *et al*. (2015) and Ibrahim (2012). Hand weeding twice at 15 DAS and 30 DAS produced maximum seed yield and it was at par with the pendimethalin at 1.0 kg/ha followed by hand weeding at 30 DAS compared to the other weed management treatments. Due to the weed free environment and early application of the broad spectrum selective herbicide which controlled the weeds at the early stage of the crop helped better utilization of light, nutrient and moisture for growth of crop followed by intercultivation gave higher seed yield of sunflower. Similar results were obtained by Bhuvaneshwari *et al*. (2010).

Interaction effect was significant in combination of spacing 60 × 30 cm and hand weeding twice at 15 DAS and 30 DAS among weed management practices resulted in higher dry matter production and seed yield of sunflower. It might be due the weed free situation and optimum row spacing checks the weed growth. It had lead to increase in dry matter production and seed yield of sunflower crop.

Effect on economics

Higher cost of cultivation was registered with the spacing 90 × 15 cm (*i.e.,* 24189 ₹/ha) during *Kharif* 2016 and 2017 (**Table 2**). Wider spacing increased the labour cost which directly reflected on the increased cost of cultivation. Lesser cost of cultivation was recorded with closer spacing 75 × 25 cm (*i.e.,* 23573 ₹/ha) during both the years. Among the weed management practices, lower cost of cultivation with pendimethalin at 1.0 kg/ha followed by weeder at 30 DAS (*i.e.,* 21460 ₹/ha) due to the early weed control by pre-emergent herbicide and later stage weed control by the moment of power weeder significantly reducesed the labour cost.

Gross return was higher with the spacing 75 × 25 cm (₹ 50664 and 55524 ₹/ha during *Kharif* seasons of 2016 and 2017, respectively), this was followed by the spacing 75 × 20 cm during both the years of experiment. Because of optimum spacing helped the plant to effectively utilize the resources which results in increased growth and yield of crop and it showed significant effect in increased gross return. Hand weeding twice at 15 and 30 DAS among the weed management practices registered higher gross returns during both the years (₹ 55404 and 60186/ha during *Kharif* seasons of 2016 and 2017, respectively) Weed free situation helped the plants to utilize the available resources like light, nutrient and moisture which reflected on better growth and yield of crop. This is in accordance with the result of Kalhapure *et al.* (2013) who revealed higher gross returns with weed free check in groundnut crop.

The spacing 75 × 25 cm (₹ 27091 and 31951/ha during *Kharif* seasons of 2016 and 2017, respectively) recorded the higher net return. With respect to weed management practices, pre-emergence herbicide pendimethalin at 1.0 kg/ha followed by hand weeding at 30 DAS (₹ 28260 and

Table 1. Effect of spacing and weed management practices on seed yield (kg/ha) of sunflower

Treatment	Pendimethalin PE at 1.0 kg/ha followed by HW at 30 DAS	Pendimethalin at 1.0 kg/ha followed by weeder at 30 DAS	Weeding with weeder at 15 DAS and 30 DAS	Two hand weedings at 15 DAS and 30 DAS	Weedy check	Mean
2016						
S_1 60 × 30 cm	1958	1328	1103	2072	969	1486
S_2 75 × 25 cm	1895	1922	1721	1997	909	1689
S_3 75 × 20 cm	1805	1842	1650	1886	932	1623
S_4 90 × 20 cm	1456	1487	1348	1551	736	1316
S_5 90 × 15 cm	1648	1669	1538	1728	803	1477
LSD (p=0.05)	S	W	S at W	W at S		
	122	129	191	196		
2017						
S_1 60 × 30 cm	2201	1488	1272	2225	981	1633
S_2 75 × 25 cm	2134	2145	1878	2170	927	1851
S_3 75 × 20 cm	2014	2021	1801	2076	953	1773
S_4 90 × 20 cm	1633	1668	1513	1699	767	1456
S_5 90 × 15 cm	1829	1846	1683	1861	820	1608
LSD (p=0.05)	S	W	S at W	W at S		
	134	141	211	215		

Table 2. Effect of spacing and weed management practices on economics of sunflower (*Kharif*, 2016)

	Kharif, 2016						*Kharif*, 2017				
Treatment	Cost of cultivation (`/ha)	Gross Returns (`/ha)	Net Returns (`/ha)	Benefit: cost ratio	Per day income (`/ha)	Treatment	Cost of cultivation (`/ha)	Gross Returns (`/ha)	Net Returns (`/ha)	Benefit: cost ratio	Per day income (`/ha)
Spacing											
S_1	23729	44580	20851	1.86	469	S_1	23729	49002	25273	2.04	516
S_2	23573	50664	27091	2.15	533	S_2	23573	55524	31951	2.35	584
S_3	23636	48690	25055	2.06	513	S_3	23636	53190	29555	2.25	560
S_4	23989	39468	15479	1.64	415	S_4	23989	43680	19691	1.82	460
S_5	24189	44316	20127	1.83	466	S_5	24189	48234	24045	1.99	508
Weed management practices											
W_1	24312	52572	28260	2.16	553	W_1	24312	58866	34554	2.42	620
W_2	21460	49488	28028	2.31	521	W_2	21460	55008	33548	2.57	579
W_3	23984	44160	20176	1.85	465	W_3	23984	48882	24898	2.04	515
W_4	26930	55404	28474	2.06	583	W_4	26930	60186	33256	2.24	634
W_5	22430	26094	3664	1.16	275	W_5	22430	26688	4258	1.19	281

S1 = 60 × 30 cm; S2 = 75 × 25 cm; S3 = 75 × 20 cm; S4 = 90 × 20 cm; S5 = 90 × 15 cm; W1 = Pre-emergence herbicide pendimethalin at 1.0 kg/ha followed by hand weeding at 30 DAS; W2 = Pendimethalin at 1.0 kg/ha followed by weeder at 30 DAS; W3 = Weeding with weeder at 15 DAS and 30 DAS; W4 = Two hand weedings at 15 DAS and 30 DAS; W5 = Weedy check

34554/ha during *Kharif* seasons of 2016 and 2017, respectively) and Increased B:C ratio with spacing 75 × 25 cm (2.15 and 2.35 during *Kharif* seasons of 2016-17 and 2017-18, respectively) This might be due to reduction in the cost of cultivation by use of power weeder for weeding instead of manual labour as well as optimum spacing for movement of power weeder without plant damage which might have increased the yield and increased the net returns and B: C ratio. These results were in confirmatory with the finding of Baskaran and Kavimani (2014) and Nagre *et al.* (2017).

Per day return was high with the spacing 75 × 25 cm (₹ 533 and 584/day/ha during *Kharif* seasons of 2016 and 2017, respectively), Hand weeding twice at 15 and 30 DAS in both the years (₹ 583 and 634 / day/ha during *Kharif* seasons of 2016 and 2017, respectively). Weed free situation due to hand weeding twice might have directly reflected on increase in yield of crop.

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Relative density of weeds and weed indices as influenced by weed control options in cotton

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Phytotoxicity

ABSTRACT

Field experiments were conducted at Professor Jayashankar Telangana State Agricultural University, Rajendranagar during *Kharif* 2017 for the evaluation of efficacy different doses of diuron in both red and black soils. The treatment consisted of test herbicides such as, diuron 80% WP at 0.5 kg/ha, 0.75 kg/ha and 1.0 kg/ha along with registered formulation of pendimethalin 38.7% CS at 677 g/ha, intercropping with green manure crop, mechanical weeding thrice at 20, 40, 60 DAS and unweeded control. The experiment was laid out in a randomised block design replicated thrice. The weed flora of the experimental field in red soil was dominated by *Cynodon dactylon*, *Rottboellia exaltata*, *Parthenium hysterophorus*, *Trianthema portulacastrum* and *Commelina benghalensis*. While in case of black soil, predominant flora was *Cynodon dactylon*, *Cyperus rotundus*, *Parthenium hysterophorus*, *Euphorbia geniculata*, *Tridax procumbens*, *Cyanotis cristata*, *Digera arvensis* and *Celosia argentia*. The treatments, mechanical weeding thrice at 20, 40 and 60 DAS, polymulch treatments reduced the weed growth in both red and black soils. Among the herbicides, diuron at 1.0 kg/ha *fb* pyrithiobac-sodium + quizalofop-ethyl in red soil and both diuron at 1.0 kg/ha and 0.75 kg/ha along with sequential application of herbicides reduced the density of weeds. Diuron could reduce the broad-leaved weeds and grasses except itch grass. Sedges are also could not be reduced by diuron. The lower values of weed persistence index was obtained with herbicidal treatments *i.e.*, diuron at 1.0 and 0.75 kg/ha *fb* pyrithiobac-sodium + quizalofop-ethyl. The crop resistance index and treatment efficiency index were superior in case of polymulch and mechanical weeding thrice at 20, 40 and 60 DAS.

In textile industry cotton plays vital role in supplying raw materials to the tune of 85% of total requirement in India. It has immense potentiality to share foreign exchange of 38% of total export of Indian economy besides providing employment to 60 million people in India (Kairon and Venugopalan 2000). Cotton is grown in an area of 11.76 Mha, while the total production of cotton in India is 6.21 million bales (170 kg each) in 2015-16 against the production of 34.80 million bales in 2014-15. Yield level in this crop keeps fluctuating year after year depending upon the problem of insect pest and diseases that are closely associated with the climatic conditions in the region. Since, the crop has long growth cycle, it has to pass through frequent rains and thus weeds also pose a serious problem. Losses caused by weeds in cotton ranges from 50 to 85% depending upon the nature and intensity of weeds. The critical period of weed competition in cotton was found to be 15 to 60 days (Sharma 2008). Pre-emergence herbicides are available for controlling weeds, the need for post-emergence herbicide are often realised to combat the weeds emerged during crop growth. Alachlor and pendimethalin are the most widely used and registered herbicides for weed control in cotton. Continuous use of any herbicide may lead to the development of resistance in weeds therefore, there is need for alternative herbicides. Hence diuron which is selective to cotton and having a longer persistence in soil can be a better substitute. In a field experiment conducted in PJTSAU, phytotoxicity was observed at the dosage of 1 kg/ha. So evaluation of different doses of diuron for weed control is needed. The relative density of weeds is presented in this paper as influenced by different doses of diuron in rainfed cotton in both red and black soils.

A field experiment was conducted during *Kharif*, 2017 at College farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana State. The farm is geographically located at an altitude of 542.3 m above mean sea level at 17°19' N latitude and 78°23' E longitude in the Southern Telangana agro-climatic zone of Telangana. According to Troll's (Troll 1965) climatic classification, it falls under semi-arid tropics (SAT). The experiment was conducted in red and black soil and laid out in a randomised block design with three replications. The treatments included three doses of diuron (0.5, 0.75 and 1.0 kg/ha), pendimethalin 38.7% CS at 677 g/ha as PE followed by sequential application of pyrithiobac-sodium 10% EC 62.5 g/ha + quizalofop-p-ethyl 5% EC 50 g/ha, intercropping of cotton with green manure crop (sunhemp), mechanical weeding thrice at 20, 40 and 60 DAS (weed free), polymulch and unweeded control.

'*Mallika*' *Bt* was sown with a seed rate of 2.5 kg/ha. One-two seeds per hill were sown at a spacing of 75 x 75 cm to facilitate the use of power weeder in both directions in case of mechanical weeding. Pre-emergence herbicides were sprayed on the third day after sowing. Diuron 80% W.P. at 0.5 kg/ha, diuron 80% W.P. at 0.75 kg/ha, diuron 80% WP 1.0 kg/ha, pendimethalin 38.7% CS 677 g/ha were sprayed on the third day, pyrithiobac-sodium 10% EC 62.5 g/ha+ quizalofop-ethyl 5% EC 50 g/ha were sprayed at 2-3 leaf stage of the weeds. In the intercropping treatment the intercrop sunhemp was sown along with cotton. Polymulch was spread 8 DAS after emergence of the seedling. Mechanical weeding at 20, 40, 60 DAS was done with power weeder and an unweeded check was maintained.

The important weed species associated with *Bt* Cotton crop in the experimental area were recorded at 30, 60 and 90 DAS. Weed count was taken at 30, 60 and 90 DAS in two randomly selected quadrats (0.5 x 0.5 m) in each plot. At every sampling, individual species were separated and expressed as number/m. The sampling was done outside the net plot but within the gross plot. The treatment wise total weed count was recorded and expressed as no./m^2. The total weeds enclosed in the quadrat were carefully cut close to the ground level with the help of weeding hook. The relative weed density was calculated by following formula:

$$\text{Relative weed density} = \frac{\text{Density of individual species in the community}}{\text{Total density of weeds in the community}} \times 100$$

The observation on weeds at 60 days of sowing and dry weight of crop and grain yield at harvest have been presented in (**Table 1**). The various indices developed by Mishra and Misra (1997) have been used to identify the weed persistence, crop resistance and phytotoxic effect due to herbicidal treatments as mentioned below calculated on the basis of mean data of two years and have been presented in (**Table 2**) along with economics of cultivation.

Weed persistence index (WPI): (Dry weight of weeds in treated plot/dry weight of weeds in control plot) x (weed count in the control plot / weed count in the treated plot) (Mishra *et al*. 2016).

Crop resistance index (CRI): (dry matter production by crop in the treatment plot/dry matter production by crop in the control plot) x (dry matter production of weed in control plot/dry matter production of weeds in treatment plot) (Mishra *et al*. 2016).

Agronomic management index (AMI): (percentage increase in yield over control - percentage reduction of weeds)/percentage control of the pest (weed/insect).

Herbicide/ treatment efficiency index (TPI): [(yield of treatment- yield of control)*100/ yield of control)]/ (weed weight in treatment/ weed weight in control)

Weed flora

The weed flora was recorded on 30, 60 and 90 DAS during the crop growth period. The density of weed flora varied with the treatments adopted. In the red soil, among the grasses *Cynodon dactylon*, *Rottboellia exaltata*, *Dactyloctenium aegyptium* and *Dinebra retroflexa* were noticed. *Cyperus rotundus* was the only sedge present in the field. Among the broad-leaved weeds, *Parthenium hysterophorus*, *Euphorbia geniculata*, *Trianthema portulacastrum*, *Trichodesma indica*, *Commelina benghalensis*, *Digera arvensis*, *Tridax procumbens*, and *Phyllanthus niruri* were observed in the field.

In the black soil, among the grasses *Cynodon dactylon*, *Rottboellia exaltata* and *Echinocloa colona*, *Dactyloctenium aegyptium* were noticed. *Cyperus rotundus* was the only sedge present in the field. Among the broad-leaved weeds, *Parthenium hysterophorus*, *Euphorbia geniculata*, *Trianthema portulacastrum*, *Trichodesma indica*, *Cyanotis cristata*, *Digera arvensis* and *Celosia argentia* were observed in the field.

Relative weed density

The influences of different weed control practices adopted on the relative density of grasses, broad leaved weeds and sedges is studied. The relative density of grasses, BLW's and sedges as in case of red soil is depicted in **Table 1, 2** and **3** respectively. While that of grasses in **Table 4**, BLW's in **Table no. 5,6** and sedges in **Table 7** as in case of black soils.

In black soil: At 30 DAS, sedges were the dominant weed flora in diuron 1.0 kg/ha, 0.75 kg/ha as PE *fb* pyrithiobac-sodium + quizalofop-ethyl as PoE to the tune of 90% and the grasses were absent while the broad-leaved weeds were upto 10%. While in case of diuron 0.5 kg/ha and pendimethalin PE *fb* pyrithiobac sodium + quizalofop-ethyl as PoE, broad-leaved weeds and sedges were predominant. *Parthenium hysterophorus*, *D. arvensis* and *E. geniculata* were the dominant weeds among the broad-leaved weeds. *C. argentea* were the least dominant broad-leaved weed and *T. procumbens* was absent at 30 DAS. While the grasses were least dominant. Similar results were observed even at 60 DAS. But the relative density was increasing in all the treatments and also in diuron treatments as the number of days increased. At 90 DAS, in diuron 1.0 kg/ha, 0.75 kg/ha and 0.5 kg/ha as PE *fb* pyrithiobac-sodium + quizalofop-ethyl as PoE sedges were dominant and the broad-leaved weeds and grasses couldn't exceed 20%. In the rest of the treatments, broad-leaved weeds and sedges remained proportionately while among the broad-leaved weeds *P. hysterophorus* was the dominant while rest of the treatments remained less than 10% and *D. arvensis* was highest only in mechanical weeding thrice at 20, 40 and 60 DAS. However the grasses recorded the least relative density.

In red soil: At 30 DAS, diuron treatments PE *fb* pyrithiobac-sodium + quizalofop-ethyl as PoE recorded the higher relative density of sedges upto 80% and *R. exaltata* was also present. *R. exaltata*, *T. portulacastrum* and *C. bengalensis* were present proportionately in other treatments. *R. exaltata* was the dominating grass and weed in the red soil while among the broad-leaved weeds, *T. portulacastrum* was the dominant. *D. aegyptium* was absent at 30 and 60 DAS. Similar results were obtained at 60 DAS. All the three were found to be even at 90 DAS. In diuron treatments *C. rotundus* and *R. exaltata* were similar in relative density while in other treatments broad-leaved weeds were also prevalent. *T. portulacastrum* and *E. geniculata* were absent at 90 DAS as the life span of the weeds was completed. *P. hysterophorus* was the predominant broad-leaved weed.

It was observed that diuron could not control *C. rotundus* and *R. exaltata*. Broad-leaved weeds and other grasses except *R. exaltata* were effectively controlled. While pendimethalin could not control *P. hysterophorus*. However in both the soils, mechanical weeding thrice at 20, 40 and 60 DAS and polymulch effectively controlled the weeds. The season long reduced density of weeds in polythene mulch might be due to the sensitivity of the most of the weed seeds to light. So these weed seeds did not germinate under the plastic, which caused a reduction in population (Mahajan *et al.* 2007). Sequential application of herbicides along with application of PoE herbicides resulted in lower weed density which could be attributed to weed free situation during initial stages and further control of new flush of weeds by application of post-emergence herbicides at 25 DAS and thus, reducing the weed competition during critical initial to peak growth period of *Bt* cotton. Similar results were reported by Chetan *et al.* (2016), Prabhu *et al.* (2011), Nalini *et al.* (2013) and Hariharasudhan *et al.* (2017).

Weed indices

Weed indices like weed persistence index, crop resistance index and herbicide/treatment efficiency are calculated as to know the tolerance of weeds against weed control options adopted, resistance offered by the crop against the weeds and individual treatment efficiency. The data required for the calculation of these indices such as crop dry matter production, weed count, weed dry matter production and yield of both the soils are depicted in **Table 8**.

Table 1. Relative density of grasses as influenced by weed management measures adopted in red soils

Treatment	*Cynodon dactylon*			*Rottoboelia exaltata*			*Dactyloctenium aegyptium*			Total grasses		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	1.67	1.32	0	7.67	45.44	37.03	0	0	3.50	9.33	46.75	40.53
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.98	0.47	0	13.30	42.70	55.32	0	0	0.98	14.28	43.17	56.30
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	1.39	0	0	13.61	34.66	49.93	0	0	0.00	15.00	34.66	49.93
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.56	2.11	1.19	8.05	51.44	41.21	0	0	5.33	8.62	53.54	47.73
Cotton + sunhemp	3.26	1.55	6.01	31.36	40.03	26.68	0	0	3.39	34.62	41.58	36.07
Mechanical weeding at 20, 40, 60 DAS	24.17	4.44	16.25	18.59	31.60	25.00	0	0	6.67	42.76	36.04	47.92
Control (unweeded)	3.15	0.39	4.99	11.98	43.04	33.59	0	0	4.34	15.13	43.43	42.91
Polymulch of 0.25 mm thickness	4.17	1.67	13.35	9.88	52.58	21.79	0	0	4.17	14.05	54.24	39.30

Weed persistence index (WPI)

The weed persistence data indicates the relative dry matter accumulation of weeds per count in comparison to control. Weed data at 60 DAS is considered for the calculation of the WPI. The WPI varied with the treatments and also the soil type and data is depicted in **Table 8**.

In red soil: The highest WPI was observed in case of intercropping with sunhemp (1.34) indicating resistance of escaped weeds to control measures while the rest of the treatments had values below. The lowest WPI values were observed with diuron 0.75 kg/ha (0.56), 1.0 kg/ha (0.59) PE *fb* pyrithiobac sodium + quizalofop-ethyl as PoE and mechanical weeding thrice at 20, 40 and 60 DAS (0.58) which indicates the lower persistence of escaped weeds indicating broad spectrum effect in controlling the weeds.

In black soil: Polymulch (4.06) recorded the highest WPI which indicates the resistance of escaped weeds to control measures which was followed by mechanical weeding thrice at 20, 40 and 60 DAS (1.82), intercropping with sunhemp (1.31), diuron 0.5 kg/ha *fb* pyrithiobac sodium + quizalofop-ethyl as PoE (1.23) and pendimethalin PE *fb* pyrithiobac sodium + quizalofop-ethyl as PoE (1.16). Diuron 0.75 kg/ha (0.86), 1.0 kg/ha (0.93) PE *fb* pyrithiobac sodium + quizalofop-ethyl as PoE registered lower WPI values having a broad spectrum control weeds.

Crop resistance index (CRI)

CRI indicates the increased vigour of crop plant due to weed control measures presented in **Table 8**. For the calculation of the CRI the values of crop dry matter production and weed dry matter production at 60 DAS is taken.

In red soil: The highest CRI was recorded by mechanical weeding thrice at 20, 40 and 60 DAS (30.03) which was followed by polymulch (27.04) and diuron 1.0 kg/ha PE *fb* pyrithiobac sodium + quizalofop-ethyl as PoE (11.65) indicating much less harmful effect of herbicides on crop as compared to other treatments. The lowest CRI was registered by intercropping with sunhemp (3.25).

In black soil: Similar to red soil, mechanical weeding thrice at 20, 40 and 60 DAS (5.99) registered higher CRI followed by polymulch (5.57), diuron 1.0 kg/ha (4.52) and 0.75 kg/ha (4.11) PE *fb* pyrithiobac sodium + quizalofop-ethyl as PoE.

Herbicide/treatment efficiency index (TEI)

TEI indicates the yield advantage by adoption of the treatment over the control in relation to the reduction in weed dry matter over control. The data is presented in **Table 8**.

Table 2. Weed density of BLW's as influenced by weed management measures adopted in red soils

Treatment	*Parthenium hysterophorus*			*Trianthema portulacastrum*			*Commelina benghalensis*			Total BLW's		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	6.00	5.52	5.87	25.83	9.18	0	0.83	4.09	0	32.67	18.79	5.87
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	2.21	1.21	2.75	4.18	0.61	0	0	0	0	6.40	1.82	2.75
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	4.17	0	1.52	0	0	0	0	0	0	4.17	0.00	1.52
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	12.58	7.98	10.89	8.12	4.11	0	7.98	5.75	0	28.69	17.84	10.89
Cotton + sunhemp	7.13	8.07	6.99	28.55	8.63	0	5.42	6.49	0	41.10	23.18	6.99
Mechanical weeding at 20, 40, 60 DAS	15.06	5.25	25.42	9.23	5.44	0	6.67	4.99	0	30.96	15.68	25.42
Control (unweeded)	12.26	10.01	6.58	33.18	3.04	0	4.19	8.43	0	49.62	21.48	6.58
Polymulch of 0.25 mm thickness	13.69	9.70	24.17	13.33	1.67	0	10.83	0	0	37.86	11.36	24.17

Table 3. Weed density of sedges as influenced by weed management measures adopted in red soils

Treatment	*Cyperus rotundus*		
	30 DAS	60 DAS	90 DAS
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	56.33	33.31	54.52
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	79.32	55.02	40.60
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	80.83	65.34	48.56
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	62.13	24.83	40.93
Cotton + sunhemp	18.45	30.05	56.14
Mechanical weeding at 20, 40, 60 DAS	26.28	46.76	26.67
Control (unweeded)	29.36	29.78	50.24
Polymulch of 0.25 mm thickness	29.29	31.06	35.14

Table 4. Relative density of grasses as influenced by weed management measures adopted in black soils

Treatment	*Cynodon dactylon*		
	30 DAS	60 DAS	90 DAS
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.81	2.08	3.36
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.00	2.17	2.19
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.00	1.23	2.95
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	1.01	0.00	5.94
Cotton + sunhemp	2.34	6.00	6.33
Mechanical weeding at 20, 40, 60 DAS	0.00	2.38	6.73
Control (unweeded)	2.60	2.23	4.15
Polymulch of 0.25 mm thickness	2.67	11.64	12.29

Table 5. Relative density of BLW's as influenced by weed management measures adopted in black soils

Treatment	*Parthenium hysterophorus*			*Celosia argentia*			*Digera arvensis*			Total BLW's		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	38.36	26.88	8.21	6.35	1.53	1.15	0.00	5.83	3.70	48.01	39.47	14.96
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	6.67	8.87	7.75	0.00	0.58	0.00	0.00	0.72	3.45	8.76	13.46	11.10
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	9.88	3.61	5.60	0.00	0.00	0.00	0.00	0.48	1.28	7.85	4.33	7.52
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	44.88	41.24	33.18	1.61	1.11	3.67	6.84	12.14	6.67	60.34	59.02	45.61
Cotton + sunhemp	15.35	23.63	19.09	4.87	3.57	4.23	35.98	30.93	8.83	62.50	66.29	41.03
Mechanical weeding at 20, 40, 60 DAS	14.37	37.43	22.22	0.00	0.00	0.00	32.61	20.50	10.44	61.11	79.70	34.45
Control (unweeded)	34.62	27.52	31.31	2.08	0.72	1.76	29.45	8.20	6.10	77.19	50.17	46.67
Polymulch of 0.25 mm thickness	22.36	36.01	37.79	2.22	2.22	6.48	3.90	10.56	5.81	39.62	64.68	62.53

Table 6. Relative density of BLW's as influenced by weed management measures adopted in black soils

Treatment	*Euphorbia geniculata*			*Cyanotis cristata*			*Tridax procumbens*		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	4.21	2.04	0	1.06	0.00	1.04	0	3.15	3.13
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.83	3.15	0	0.00	0.00	4.37	0	0.00	0.00
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.00	0.00	0	0.00	0.00	1.04	0	0.00	1.28
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.80	1.67	0	6.33	1.43	0.00	0	1.11	4.94
Cotton + sunhemp	1.93	0.00	0	4.49	7.83	2.17	0	0.00	4.48
Mechanical weeding at 20, 40, 60 DAS	9.29	2.08	0	0.00	24.34	6.73	0	7.41	3.70
Control (unweeded)	5.54	1.27	0	5.34	8.45	3.02	0	3.44	6.03
Polymulch of 0.25 mm thickness	7.45	14.34	0	4.44	0.00	0.00	0	0.00	5.81

Table 7. Effect of weed control measures on crop dry matter, weed count, weed dry matter and yield

Treatment	Crop dry matter at 60 DAS (g/plant)		Weed dry matter at 60 DAS (g/m^2)		Weed count at 60 DAS (no./m^2)		Kapas yield (t/ha)	
	Red soil	Black soil	Red soil	Black soil	Red soil	Black soil	Red soil	Black soil
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	91.33	63.67	31.50	33.57	63.67	63.33	1.41	1.55
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	96.33	90.00	25.50	23.02	62.00	61.67	1.62	2.65
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	109.33	90.33	17.70	20.99	41.33	52.00	2.05	2.04
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	91.08	76.67	32.90	34.50	59.33	61.00	1.39	1.50
Cotton + sunhemp	67.00	61.67	38.90	29.37	39.67	58.33	0.65	1.03
Mechanical weeding at 20, 40, 60 DAS	121.00	103.00	7.60	18.08	18.00	23.00	2.11	2.75
Control (unweeded)	29.00	41.00	54.70	43.08	75.00	99.67	0.1	0.10
Polvmulch of 0.25 mm thickness	119.00	105.00	8.30	19.86	17.00	11.33	2.42	3.46

In red soil: The highest TEI was recorded by polymulch (18596) which was followed by mechanical weeding thrice at 20, 40 and 60 DAS (17560) and diuron 1.0 kg/ha PE *fb* pyrithiobac sodium + quizalofop-ethyl as PoE (7309) indicating the higher yield advantage in relation to the reduction in weed dry matter. The lowest CRI was registered by intercropping with sunhemp.

In black soil: Polymulch (7150) registered higher TEI followed by mechanical weeding thrice at 20, 40 and 60 DAS (6183) and diuron 0.75 kg/ha PE *fb* pyrithiobac sodium + quizalofop-ethyl as PoE (4684).

Table 8. Effect of weed control measures on weed indices in cotton

Treatment	Weed persistence index		Crop resistance index		Treatment efficiency index	
	Red soil	Black soil	Red soil	Black soil	Red soil	Black soil
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.68	1.23	5.47	1.99	2774	1824
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.56	0.86	7.13	4.11	3977	4684
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.59	0.93	11.65	4.52	7309	3900
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	0.76	1.31	5.22	2.34	2616	1709
Cotton + sunhemp	1.34	1.16	3.25	2.21	957	1337
Mechanical weeding at 20, 40, 60 DAS	0.58	1.82	30.03	5.99	17560	6183
Control (unweeded)	0.67	4.06	27.04	5.56	18596	7150

Table 9. Relative density of sedges as influenced by weed management measures adopted in black soils

Treatment	*Cyperus rotundus*		
	30 DAS	60 DAS	90 DAS
Diuron 0.5 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	48.68	58.50	77.33
Diuron 0.75 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	92.50	84.49	82.25
Diuron 1.0 kg/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	90.12	94.67	87.85
Pendimethalin at 677 g/ha *fb* pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha	38.52	40.85	45.61
Cotton + sunhemp	31.35	27.63	54.86
Mechanical weeding at 20, 40, 60 DAS	42.28	12.80	61.28
Control (unweeded)	18.26	44.24	47.64
Polymulch of 0.25 mm thickness	61.40	52.93	54.80

The higher yield was obtained in diuron at 0.75 kg/ha but not in 1 kg/ha due to the reduction in plant population by the phytotoxic effect on the crop at higher dose.

In both the soil polymulch obtained higher TPI due to the increased yield with increased moisture and nutrient supply in polymulch treatment (Loy *et al.* 1998) even though the mechanical weeding had higher weed control efficiency.

The relative weed density was minimum in mechanical weeding thrice at 20, 40 and 60 DAS and polymulching at all the stages of crop growth and among the herbicides, diuron at 1.0 kg/ha *fb* pyrithiobac sodium + quizalofop-ethyl reduced the weed density in red soil. In case of black soil in mechanical weeding thrice at 20, 40 and 60 DAS and polymulching significantly reduced the weed density and among the chemical treatments diuron at 1.0 kg/ ha and 0.75 kg/ha along with sequential application of herbicides reduced the weed density. The lower values of weed persistence index was herbicidal treatments *i.e.*, diuron at 1.0 and 0.75 kg/ha *fb* pyrithiobac-sodium + quizalofop-ethyl. The crop resistance index and treatment efficiency index were superior in case of polymulch and mechanical weeding thrice at 20, 40 and 60 DAS.

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Performance evaluation of some selected weeding tools in faba bean

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ABSTRACT

The field performance of different weeding tools/implements *viz. khurpi* (hand hoe), grubber, wheel hoe, and power weeder were carried out at the Institute Research Farm, ICAR-Research Complex for Eastern Region, Patna, Bihar. Results revealed that actual field capacity of 0.0046±0.002, 0.0086±0.0002, 0.0189±0.0003, 0.0696±0.003 ha/h had associated with *khurpi*, grubber, wheel hoe and power weeder, respectively. *Khurpi* had recorded the maximum weeding efficiency (98.9%) and lowest in case grubber **(**74%). Similarly, power weeder contributed to higher plant damage (1.94%). Operational of *khurpi* had recorded maximum (Rs.6793/ha). A reasonable amount of savings of weeding operation were observed using grubber, wheel hoe, and power weeder as compared to *khurpi*.

Faba bean (*Vicia faba* L.) is a potential crop for nutritional security. However, it is still treated as an underutilized crop in India. Its seeds are very low in saturated fat, cholesterol, and sodium and having good source of dietary fibre, protein (20-41%), P, Cu and Mn (Singh *et al.* 2014). Currently 58 countries produce this bean on large scale, and in India it is cultivated in 25000 ha (Singh *et al.* 2013). Faba bean is poor competitor with weeds at initial stages of crop growth, thus, this makes an integrated weed management (IWM) essential for successful production. Research finding reveals that weeding at 30 and 45 days after sowing (DAS) proven effective for weed management (Ram *et al.* 2012). Hand weeding is a most followed practice to manage weeds in faba bean. However, it is labour intensive and account for~25% of total labour requirement that is 90–1200 man-hr/ha (Yadav and Pund 2007, Yadav *et al.* 2019). Delayed in weeding reduces crop yield by 40-60% and sometimes complete crop failure (Singh 1988). Hence, timely weeding is an important aspect for achieving the optimum yield (Singh *et al.* 2019). Use of improved weeders is a viable option to reduce time and drudgery (Sarkar *et al.* 2016). Managing weeds with use of improved weeding tools / implements not only uproots weed between crop rows but also keeping surface soil loose, ensuring better soil aeration and water intake capacity. There are many types of weeders available in India for weeding but all these designs are the region specific to meet the requirement of soil type, crops and availability of the local resources (Goel *et al.* 2008). Hence, in the present study different weeders (*khurpi* (hand hoe), grubber, wheel hoe, power weeder) were evaluated in faba bean for comparing the weeding efficiency under the irrigated ecosystem of Indo-Gangetic plains of Eastern India.

Comparative performance of different weeding tools in faba bean was evaluated in triplicate during the winter season of 2017 at the Institute farm, ICAR Research Complex for Eastern Region, Patna (25° 35.485 N latitude and 85° 04.951 E longitude). Soil of the experimental plot was clay loam (sand: 23.36%, silt: 39.64% and clay: 37%). Soil moisture content was 11.4% at 0-15 cm and 13.7% at 15-30 cm soil depth, respectively. Monthly mean maximum and minimum temperature during the cropping period ranged from 22.2-32.7˚C and 8.7-18.3˚C, respectively**.** Crop geometry was maintained by keeping of row and plant spacing of 40 × 20 cm, respectively. Data on weeds were recorded per plot at 45 DAS using a quadrate of 0.5 m^2 from randomly selected 4-5 places and averaged them. Data on weed density were subjected to the square root transformation ($\sqrt{x+0.5}$) before statistical analysis to normalize their distribution. Field observations like operational speed, operation width, labours required for weeding operation, soil moisture content were recorded. Data collected during the field evaluation trails were analyzed to determine the actual field capacity, field efficiency, weeding efficiency and plant damage.

Field capacity: Effective actual field capacity was calculated using eqn. (Mehta *et al.* 2005)

$$\text{Effective field capacity} = \frac{A}{T_p + T_{np}}$$

Where, A= Area, ha, T_p= productive time, hr, T_{np}=non productive time, hr

Weeding efficiency

The weeder used during the study were measured for weeding efficiency by using following formula as suggested by Rangasamy *et al. (*1993).

$$\text{Weeding efficiency (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where, W_1 = No. of weeds before weeding, W_2= No. of weeds after weeding

Data were analyzed statistically as per standard method (Panse and Sukhatme 1978). Test of the significance of treatment differences were done on basis of t-test. Significant difference between treatments mean were compared with critical differences at 5% levels of probability.

Weed flora

Major weed flora present in experimental block was *Solanum nigrum, Chenopodium album, Rumax retroflexus, Vicia sativa, Anagalis arvensis, Barbarea vulgaris* (**Table 1**). Total weed density was the lowest in *khurpi* (3.02/m^2) and the highest with wheel hoe (4.94/m^2) during the experimentation.

Field capacity

Field capacity of power weeder was found to be maximum 0.0696 ha/h higher than *khurpi* (0.0046 ha/h) and area coverage by grubber (0.0086 ha/h) and wheel hoe (0.0189 ha/h), which was more than *khurpi* (**Table 2**). Results revealed that power operated weeder was the most effective weeding tools as compared to hand weeding tools. Wide difference in field capacity of different tools/implements might be due to width of soil cutting as well as forward speed. Shekhar *et al.* (2010) found that similar results of area coverage with power operated weeder (0.670 ha/h) followed by wheel hoe (0.009 ha/h), grubber (0.008 ha/hr) and *khurpi* (0.002 ha/h). Sarkar *et al.* (2016) also reported in winter maize that field capacity of wheel hoe was maximum (0.008 ha/hr), whereas spade had the minimum (0.0002 ha/hr|).

Weeding efficiency

The highest weeding efficiency was recorded with the *khurpi* (98.9%) followed by power weeder **(**83%), wheel hoe **(**80%) and grubber **(**74%), respectively (**Table 2**). A similar result was reported by Shekhar *et al.* (2016) in maize with *khurpi* (99.4%) and power weeder (89.7%). Rajak *et al.* (2018) also reported that weeding efficiency was maximum in grubber (93.1%) followed by *khurpi* (96.8%) and the lowest with herbicides (83.4%).

Plant damage

Higher percentage of plant damage was found in power weeder (1.94±0.038%) followed by wheel hoe (1.24±0.043%), grubber (1.21±0.041%) and *kurphi* (0.84±0.008%), respectively. Highest plant damage for power weeder may be attributed to higher speed of blades and operator skill (Singh *et al.* 2017).

Cost of operation

Khurpi had attributed the maximum cost of operation (` 6793/ha) followed by grubber (` 3906/ha), power weeder (`1674/ha) and wheel hoe (` 1653/ ha). Operational cost of *khurpi* increased and resulted in minimum field capacity (**Table 2**). But operational cost of power weeder had minimum compared to other weeding tools. Cost of power weeder is much expensive and thus, the small and marginal land holding farmers cannot effort initial investment in spite of high field capacity. Results revealed that amongst four weeding tools, wheel hoe was the most economic and efficient weeding tools as compared to other weeding tools in row spaced crops.

Table 1. Weed density (no./m^2) as influenced by different treatments (mean value)

Wedding tools	*Solanum nigrum*	*Chenopodium album*	*Rumex retroflexus*	*Vicia sativa*	*Anagallis arvensis*	*Barbara vulgaris*	Others	Total weed density (no./m^2)
Khurpi	1.10(1.7)	0.60(0.9)	1.10(1.7)	0.50 (0.7)	0.60 (0.9)	0.40(0.7)	2.10(4.9)	3.02(9.6)
Grubber	4.16(17.8)	0.71(1.0)	0.71(1.0)	0.71(1.0)	0.71(1.0)	0.71(1.0)	3.29(11.3)	3.82(15.1)
Wheel hoe	3.60(13.5)	1.50(2.7)	1.80(3.7)	4.10(17.3)	2.30 (5.8)	2.30(5.8)	4.10(17.3)	4.94 (24.9)
Power weeder	3.20(10.7)	1.10(1.7)	1.50(2.7)	2.80(8.3)	1.60 (3.1)	1.80(3.7)	3.10(10.1)	4.39 (19.8)
LSD (P=0.05)	0.24	0.08	0.11	0.23	0.12	0.14	0.21	0.30

Weed density figures are transformed to $\sqrt{x+0.5}$ and actual figures are given in parentheses

Table 2. Operational parameters of different weeding tools in faba bean

Parameters	*Khurpi*	Grubber	Wheel hoe	Power weeder
Field capacity(ha/hr)	0.0046 ±0.002	0.0086 ±0.0002	0.0189 ±0.0003	0.0696 ±0.003
Weeding efficiency (%)	98.90 ±7.86	74.00 ±3.98	80.00 ±6.21	83.00 ±6.52
Cost of operation (`/ha)	6793/-	3906/-	1653/-	1674/-

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Intensity of *Mikania micrantha* in coffee and other plantations of Karbi Anglong district, Assam

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ABSTRACT

In Assam, the coffee plantations are confined in Chirang, Karbi Anglong and Dima Hasao districts and also has the potentiality for expansion in the foot hill regions of lower Brahmaputra Valley and Hill agro-climatic zones of the state. Weed management is the biggest problem for coffee cultivation in the state and *Mikania micrantha* is one of the most problematic weeds in most of the coffee plantations. To quantify the infestation of the weed in and around coffee growing areas, a survey was conducted in five coffee plantations and 19 locations of other plantation crops as well as open forests covering an area of 355 km^2 in Karbi Anglong district of Assam. *M. micrantha* infestation was negligible to low in coffee plantations, which received two rounds of manual weeding whereas, the infestation was moderate to high where only one manual weeding or no weeding was done. In open forest, the density of the weed was quite high. Among the coffee estates surveyed, the highest infestation of *M. micrantha* was observed in the estates surrounded by open forests and neglected other plantation crops which served as a good seed source for this weed.

India is the seventh largest producer of coffee in the globe and contributes 3.30 and 4.85% of world coffee production and export, respectively (Anonymous 2018a). In Assam, coffee cultivation covers an area of 1249 ha (Anonymous 2018b) and is confined in Chirang, Karbi Anglong and Dima Hasao districts and bears potentiality for expansion to a great extent at least in the foot hill regions of Lower Brahmaputra Valley and Hill agro-climatic zones of the state. Among the hurdles of coffee cultivation in northeast India, weed management is one of the most critical ones. Of the most common weeds, *Mikania micrantha* H.B.K. is the highest troublesome species. And hence, a survey was undertaken with an aim to quantify the *Mikania micrantha* infestation in and around coffee growing areas of Karbi Anglong district of Assam covering an area of 355 km^2.

The survey of the distribution *M. micrantha* was carried out in five coffee plantations and their adjoining other plantations in Karbi Anglong district of Assam during 2016 and 2017 as shown below:

At each plantation area, a 1.0 ha plot was selected and abundance of *M. micrantha* was assessed from altogether 50 spots placing 1m x 1m quadrates randomly. The number of stalks of *M. micrantha* counted in each quadrate was considered as individual plants by following Puzari *et al.* (2010). These numbers were assigned grades (**Table 1**) to indicate a ranking on the basis of abundance of *M. micrantha*. This grading was based on Puzari *et al.* (2010) which in turn is a modified version of Shankaran and Pandalai (1999) as shown in (**Table 1**).

Name of coffee estates surveyed	Geographical location		Elevation (m MSL)
	Latitude (DD)	Longitude (DD)	
Suraj Timung estate, Chandmari, Diphu	25.8275182100	93.4163681600	197
Babu Tisso estate, Harichand Tisso	25.9065526987	93.5090036318	189
Dillai Coffee estate, Diliai	25.9496371858	93.5898420587	183
Sanjay Tisso estate, Sarihajan	26.0639234794	93.7624988705	116
Regional Coffee Research Station (RCRS), Chutianala, Diphu	25.9249811600	93.4393791100	165

Table 1. Grading of *M. micrantha* intensity based on population

No. of individual plants of *M. micrantha* per ha	Grade
0	Absent
1-200	Negligible
201-400	Scattered
401-600	Low
601-800	Moderate
801-1000	Medium
Above 1000	High

The data on severity of *M. micrantha* in coffee and other plantations of Karbi Anglong district of Assam (**Table 2**) showed that *M. micrantha* infestation was negligible to low in 60% coffee plantations, which experienced at least two rounds of manual weeding. In the remaining 40% plantations where only one manual weeding or no weeding was done *M. micrantha* infestation was moderate to high.

Table 2. Severity of *M. micrantha* infestation in different plantations

Type of plantations surveyed	Grade of infestation [Shankaran and Pandalai (1999) and Puzari *et al*. (2010)]							Total Nos. of plantations surveyed
	Absent	Negligible	Scattered	Low	Moderate	Medium	High	
Coffee	0	1	1	1	1	0	1	5
Teak (young)	0	0	0	0	0	0	2	2
Rubber (young)	0	0	0	0	0	0	2	2
Banana	0	0	0	0	0	0	1	1
Open forest	0	0	0	0	0	0	14	14
Total	0	1	1	1	1	0	20	24

[Tree canopy coverage 0-40% in Open forest]

Table 3. Status of *M. micrantha* in coffee estates of Karbi Anglong district and their adjacent plantation crops during 2016 and 2017

Plantation area	Elevation (m MSL)	Tree and shrub stands supporting *M. micrantha*	Light intensity below plant canopy (summer)	*Mikania* control practice adopted	*Mikania* population* (no./ha)	*Mikania* dry wt.* (g/m^2)	*Mikania* intensity grade
Suraj Timung estate	197	Coffee, arecanut, banana, jack fruit	20-40%	MW 2 times	600	1.91	Low
Banana	211	Banana, *Chromolaena odorata, Lantana camara*	100%	nil	3600	12.79	High
Rubber (young)	215	Young rubber, *Chromolaena odorata, Lantana camara*	100%	nil	3400	11.92	High
Babu Tisso estate	189	Coffee, Sirish, Neem, Kanchan	40-70%	MW once	800	3.37	Moderate
Open forest	188	*Clerodendrum viscosum, Mellotus philippinensis, Stachyterpheta jamaicensis*	80-100%	nil	3000	8.86	High
Open forest	182	*Chlerodendrum viscosum, Mallotus philippinensis, Stachyterpheta jamaicensis*	100%	nil	3400	9.64	High
Open forest	181	*Clerodendrum viscosum, Lantana camara, Stachyterpheta jamaicensis*	100%	nil	3200	9.40	High
Open forest	186	*Chromolaena odorata, Lantana camara, Stachyterpheta jamaicensis*	100%	nil	3000	8.98	High
RCRS estate	165	*Acacia lenticularis, Casia sp., Albizia odoratissima, Albizia lebbeck*	30-50%	MW 2 times	400	0.98	Scattered
Open forest	170	*Chromolaena odorata, Lantana camara, Clerodendrum viscosum, Morus alba*	100%	nil	2000	6.24	High
Open forest	174	Small forest tree	80-100%	nil	2000	6.96	High
Open forest	167	*Chromolaena odorata, Lantana camara , Chlerodendrum viscosum*	100%	nil	2200	6.98	high
Open forest	160	*Chromolaena odorata, Lantana camara, Morus alba, Chlerodendrum viscosum*	100%	nil	2200	7.09	high
Rubber (young)	164	Young rubber, *Chromolaena odorata, Lantana camara*	100%	nil	3000	11.60	high
Sanjay Tisso estate	116	Arecanut, jack fruit, teak, jamun	20-40%	MW2 times	200	0.28	negligible
Open forest	118	*Chromolaena odorata, Mallotus philippinensis, Stachyterpheta jamaicensis*	100%	nil	3800	10.12	high
Teak (young)	118	Young teak	100%	nil	2800	8.92	high
Teak (young)	116	Young teak	100%	MW once	2800	9.13	high
Open forest	119	Small forest tree	100%	nil	2600	7.95	high
Dilai coffee estate	183	*Albizia lebbeck, Acacia lenticularis, Artocarpus heterophyllus, Morus alba Clerodendrum viscosum, Stachyterphota jamaicensis,*	50-70%	nil	4000	10.88	high
Open forest	193	Small forest tree	100%	nil	2800	9.00	high
Open forest	196	Small forest tree	80-100%	Nil	3600	9.80	high
Open forest	184	Small forest tree, *Chromolaena odorata, Lantana camara*	100%	nil	3200	9.14	high
Open forest	190	Small forest tree, *Chromolaena odorata, Lantana camara*	100%	nil	3800	9.40	high

*(Rounded up average value of 50 quadrates); MW = Manual weeding

As many as 19 different crops in and around coffee estates in the Karbi Anglong district of Assam have been surveyed to know the status of *M. micrantha* as the *Mikania*-stands of neighbouring areas are the sources of seeds for infestation in coffee plantations. It is seen that, in open forest (tree canopy density less than 40%), the degree of infestation of the weed was quite high. *M. micrantha* grows best in habitats having good light conditions combined with vertical supporting structures, such as trees and shrubs. High infestation of the weed was also notices in young rubber and teak plantations. The plantations with high magnitude of infestation of *M. micrantha* adjacent to the coffee plantations (**Table 3**) were because of ill management practices and were the major sources of seeds for repeated migration of the weed in coffee plantations. The average dry weight of *M. micrantha* in high graded plantation crops varied from 6.24 g/m^2 to the extent of 12.79 g/m^2 in the low elevation hilly tracts of Assam. Among the five coffee estates of the district, the highest infestation of *M. micrantha* was observed in Dilai coffee estate followed by Babu-Tisso estate and both the estates were surrounded by open forests as a good seed source of the weed.

From the study conducted in coffee estates and their neighbouring other plantations in Karbi Anglong district, it was concluded that (i) unless adoption of management practices, *Mikania* infestation might become severe in plantation crops, (ii) the crop designing to maintain closer canopy coverage is one of the good practices to get rid of this notorious invasive weed and (iii) the ill managed plantation crops, which were quite high in number, were the major sources of *M. micrantha* seeds for repeated migration of the weed to the coffee estates of Karbi Anglong.

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Nanoparticle effect on degradation of vanillic acid, a germination inhibiting dormancy factor present in *Cyperus rotundus*

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ABSTRACT

Cyperus rotundus is one of the most invasive perennial sedge weed considered as the world's worst weed. The tubers of the weed remain viable for more than three years and pass over the harsh weather period by preventing the germination of buds present in the tubers. Due to dormancy, the tubers may sustain in the soil for longer and interfere with the crops raised in the following season. Phenols are considered as the major factor of dormancy in *Cyperus rotundus* tubers. Among different phenolic acids, vanillic acid is dominated, found under long and continuous stress. Nanoparticles are capable to degrade the phenols. In order to confirm whether the nanoparticles have effect on degradation of phenol present in *Cyperus rotundus*, the dominant phenol present in the tuber *i.e.*, vanillic acid was chosen. Experiment was conducted at the department of Nano Science and Technology, Tamil Nadu Agricultural University, Coimbatore to find the effect of different nanoparticles such as iron oxide, silver, titanium dioxide and zinc oxide on commercially available vanillic acid degradation during 2013-15. The maximum degradation of vanillic acid was observed with iron oxide nanoparticles at 25 mg *i.e.*, 60.6% degradation compared to control. Titanium dioxide, zinc oxide and silver nanoparticles at 25 mg recorded the 54.5, 49.3 and 24.8% degradation, respectively.

The purple nutsedge (*Cyperus rotundus*) causes serious problems in many crops all over the world than any other weed (Kadir *et al.* 2000). Often forms dense colonies and greatly reduces the crop yields. The sedge weed propagates mainly by producing a complex underground system of rhizomes, basal bulbs and tubers (Stoller 1975). The tubers remain viable for more than three years and pass over the harsh weather period by preventing the germination of buds present in the tubers. Jangaard *et al* (1971) reported that increasing phenolic compounds and abscissic acids in the tubers reduced the sprouting. *C. rotundus* tubers contain vanillic, coumaric, ferulic, hydroxybenzoic and protochatechuic acids (Komai *et al.* 1991). Among these, vanillic acid is dominant. Due to its highest free radical scavenging potential, vanillic acid is expected to protect plant roots from the adverse effects produced by free radicals (Swigonska *et al.* 2014). Due to dormancy, the tubers may sustain in the soil for longer time and interfere with the crops raised in the following season. Under this situation, new strategies have to be designed to break the dormancy of the tubers.

Synthesis and characterization of nanoparticles

The metal oxide nanoparticles (nps) such as iron oxide (Saha and Bhunia 2013), silver (Saware *et al.* 2014), titanium dioxide (Wang *et al.* 2007) and zinc oxide (Talam *et al.* 2012) were synthesized in wet lab. The synthesized nanoparticles were characterized by uv-vis spectrophotometer, Fourier Transform Infrared Spectroscopy (FTIR), X- Ray Diffraction (XRD), Scanning (SEM) and Transmission Electron Microscopes (TEM).

Vanillic acid degradation studies

In order to ascertain the effect of nanoparticles on phenol degradation, commercially available vanillic acid was treated with the synthesized nanoparticles such as iron oxide, silver, titanium dioxide and zinc oxide nanoparticles. 1, 2, 4, 6, 8 and 10 ppm of vanillic acid standard solutions were prepared using HPLC grade methanol. 10 ml of 10 ppm standard solution was treated with 5, 10, 15, 20 and 25 mg of iron oxide, silver, titanium dioxide and zinc oxide nanoparticles, separately. They were sonicated and kept undisturbed for 24 hours. Blank was run simultaneously. The absorbance was read at 230 nm in uv-vis spectrophotometer. By plotting graph of concentration of nanoparticles with concentration of vanillic acid, the degradation was determined.

Effect of iron oxide nanoparticles on vanillic acid degradation

Iron oxide nanoparticle on vanillic acid (commercially available) degradation was presented in **Table 1**. Iron oxide nanoparticles recorded higher per cent degradation of vanillic acid and it was concentration dependent. The maximum degradation of vanillic acid was observed with iron oxide nanoparticles at 25 mg *i.e.,* 60.6% degradation compared to control (3.94 ppm), which was observed to be on par with iron oxide nanoparticles at 20 mg (4.12 ppm). Metal oxide nanoparticle shows photocatalytic activities. Higher the surface area available, more will be the adsorption of the target molecules and higher will be the efficiency of the photocatalytic reactions. The iron oxide nanoparticles are act as nano-adsorbent and one of the potential elements for the degradation of phenol. It is used for oxidative degradation of phenols. This is in line with findings of Tavallali and Shiri (2012). Due to the biologically inert and non-toxic nature, iron oxide was chosen for the degradation of phenol present in the tubers of *C. rotundus* which is the main inhibitor of germination.

Effect of silver nanoparticles on vanillic acid degradation

Silver nanoparticle on vanillic acid (commercially available) degradation was presented in **Table 1**. Silver nanoparticles exhibited well degradation of vanillic acid and the concentration was directly proportional to the degrading ability. Silver nanoparticles at 25 mg recorded the maximum degradation of vanillic acid content *i.e.,* 24.8% degradation compared to control (7.52 ppm). It was followed by silver nanoparticles of 20 mg (7.91 ppm). The photocatalytic property of the silver nanoparticles was applied in degradation of vanillic acid. Findings are in accordance with the studies of Vanaja *et al.* (2014), who had reported that, the degradation efficiency of silver nanoparticles was due to the photocatalytic behaviour and it is about 95.3% at 72 h of exposure.

Effect of titanium dioxide nanoparticles on vanillic acid degradation

Titanium dioxide nanoparticles on vanillic acid (commercially available) degradation was presented in **Table 2**. Titanium dioxide nanoparticles showed a good per cent degradation of vanillic acid in the experiment. Titanium dioxide nanoparticles at the rate of 25 mg recorded the maximum degradation of vanillic acid content *i.e.,* 54.5% degradation (4.55 ppm), which was observed to be at par with the titanium dioxide nanoparticles of 20 mg (4.87 ppm). Vanillic acid was degraded by the photocatalytic power of titanium dioxide nanoparticles. The removal efficiency of phenol was increased with the initial phenol concentration and rising of the contact time. It was confirmed by the findings of Nickheslat *et al.* (2013) who reported that the highest removal efficiency of phenol was 50% at initial phenol concentration and it was due to the photocatalytic power of titanium dioxide nanoparticles.

Table 1. Effect of iron oxide (Fe_2O_3) and silver (Ag) nps on vanillic acid (commercially available) degradation

Treatment (Concentration of nps)	Concentration of vanillic acid (ppm)	
	Fe_2O_3 nps	Ag nps
5 mg nps	9.19	9.84
10 mg nps	7.38	8.97
15 mg nps	5.94	8.40
20 mg nps	4.12	7.91
25 mg nps	3.94	7.52
LSD (p=0.05)	0.31	0.26

Effect of zinc oxide nanoparticles on vanillic acid degradation

Zinc oxide nanoparticle on vanillic acid (commercially available) degradation was presented in **Table 2**. The maximum degradation of vanillic acid was observed with zinc oxide nanoparticles at the rate of 25 mg *i.e.*, 49.3% degradation compared to control (5.07 ppm) which was observed to be on par with the zinc oxide nanoparticles of 20 mg (5.14 ppm). The photocatalytic behaviour of the zinc oxide nanoparticles was applied in vanillic acid degradation. Zinc oxide nanoparticles, with a high surface reactivity owing to large number of active sites, have emerged to be an efficient photocatalyst. Kruefu *et al.* (2012) reported that zinc oxide nanoparticles have better photocatalytic activity over phenol degradation.

Table 2. Effect of titanium dioxide (TiO_2) and zinc oxide (ZnO) nps on vanillic acid (commercially available) degradation

Treatment (Concentration of nps)	Concentration of vanillic acid (ppm)	
	TiO_2 nps	ZnO nps
5 mg nps	9.24	9.43
10 mg nps	7.49	8.01
15 mg nps	6.35	7.54
20 mg nps	4.87	5.14
25 mg nps	4.55	5.07
LSD (p=0.05)	0.61	0.18

Comparing all nanoparticles iron oxide nanoparticles recorded higher rate of vanillic acid degradation followed by titanium dioxide, zinc oxide and silver nanoparticles (**Figure 1**).

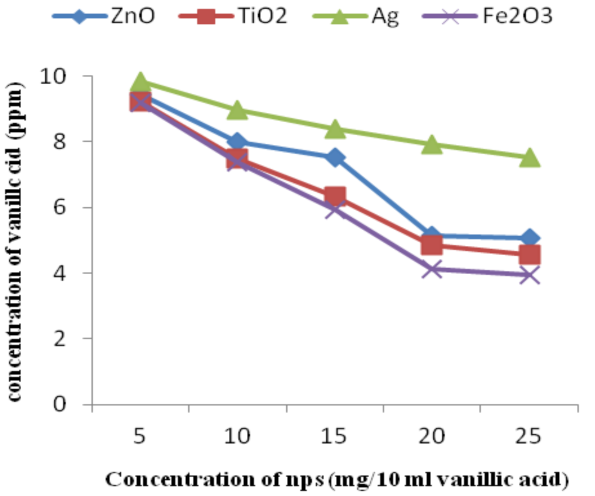

Figure 1. Effect of nanoparticles on vanillic acid degradation

Vanillic acid has been identified as one of the important phenolic compound present in the C. *rotundus* tuber. The metal oxide nanoparticle tested in this experiment effectively degraded the phytophenol at all concentrations. Maximum degradation of vanillic acid was observed with iron oxide nanoparticles at 25 mg *i.e.*, 60.6% degradation compared to control. Titanium dioxide, zinc oxide and silver nanoparticles at 25 mg recorded 54.5, 49.3 and 24.8% degradation, respectively. By degrading the germination inhibitor, the buds present in each tuber burst open and thus the entire network of tuber germinate at a time. Once the weed appear above ground can be managed effectively with the different means of control measures.

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