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Bioefficacy of flucetosulfuron in wet-seeded rice

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ABSTRACT

Field experiments were conducted during rainy and winter seasons of 2016-17 in Kalliyoor Panchayat (8.4455^0 N and 76.9918^0 E), Nemom block, Thiruvananthapuram district, Kerala, India in order to assess the bioefficacy of flucetosulfuron in wet-seeded rice. The experiment was laid out in a randomised block design with 12 treatments and three replications. Flucetosulfuron 20, 25 and 30 g/ha applied at 2-3, 10-12 and 18-20 days after sowing (DAS) along with hand weeding at 20 and 40 DAS and weedy check comprised the treatments. Pooled analysis of the data for two seasons revealed the significance of time of application of flucetosulfuron in wet-seeded rice. Application of flucetosulfuron 25 g/ha at 10-12 DAS recorded the highest grain yield (8.33 t/ ha), which was at par with flucetosulfuron 20 and 30 g/ha at 10-12 DAS and hand weeding at 20 and 40 DAS. Yield reduction due to weeds was found to be 52.33 and 55.61 per cent during rainy and winter seasons respectively. Higher yield attributes, harvest index, net income and B:C ratio were recorded for flucetosulfuron, applied at 10-12 and 18-20 DAS, irrespective of their dosage. The lower weed dry weight and weed index of these treatments substantiate the result. Henceforth, flucetosulfuron 20, 25 and 30 g/ha with a wide application window of 10-20 DAS can be endorsed for better weed management and higher yield in wet seeded rice.

INTRODUCTION

Rice (*Oryza sativa* L.), is traditionally grown by transplanting seedlings into puddled soil. Unavailability of labourers, higher labour cost and water scarcity lead farmers to adopt direct-seeded system of rice cultivation. Rice yields are affected by pests and among pests, weeds are one of the major constraints which affect rice productivity (Bhimwal and Pandey 2014). Weed management at critical period of crop growth is essential for obtaining higher yields. Hand weeding is an effective method but very expensive, time consuming and at early stages it is very difficult due to morphological similarities between grassy weeds and rice seedlings (Rahman *et al*. 2012). In large scale rice farming, herbicide-based weed management has become the smartest and most viable option due to scarcity and high wages of labour (Anwar *et al*. 2012). Despite some undesirable side effects, no viable alternative is presently available to shift the chemical dependence for weed management in rice (Juraimi *et al*. 2013). Continuous use of herbicides with similar mode of action might lead to development of resistance in certain weeds to herbicides. Hence, it is imperative to identify alternative herbicides for effective weed control and to ensure better crop yield (Gopinath and Kundu 2008). The efficacy of herbicide is evident, but ever mounting civic concern over the real or perceived impact of herbicides on public health and environment (Phuong *et al.* 2005) along with the risk of developing resistant weed biotypes (Heap 2006), phytotoxicity (Begum *et al.* 2008) and decline in soil microbial population (Ayansina and Osa 2006) has renewed the interest to alternate the use of herbicide molecules with different mode of action.

Flucetosulfuron is a pyrimidinyl sulfonylurea herbicide. It is a broad-spectrum systemic herbicide, inhibiting acetolactase synthase (ALS) enzyme, thus causing chlorosis of the plant, leading to death of apical meristems (Paranjape *et al.* 2014). Kim *et al.* (2003) observed that at the whole plant level, the GR 50 values (the dose rate required for 50% growth inhibition) of flucetosulfuron for *Echinochloa crus-galli* were 0.6 and 4.6 g/ha by soil and foliar application respectively, while those for rice were 183 and 223 g/ha respectively, demonstrating high activity of flucetosulfuron against *Echinochloa crus-galli* with good safety to rice. Flucetosulfuron is a new generation herbicide and identification of most ideal time of its application for season-long weed control in wet-seeded rice requires field investigation. Hence, the present study was undertaken.

MATERIALS AND METHODS

Field experiments were conducted during rainy and winter seasons of 2016-17 in Kalliyoor Panchayat (8.4455^0 N and 76.9918^0 E), Nemom block, Thiruvananthapuram district, Kerala, India. The experiment was laid out in a randomised block design with 12 treatments, *viz.* flucetosulfuron 20 g/ha at 2-3 DAS, flucetosulfuron 25 g/ha at 2-3 DAS, flucetosulfuron 30 g/ha at 2-3 DAS, flucetosulfuron 20 g/ha at 10-12 DAS, flucetosul-furon 25 g/ha at 10-12 DAS, flucetosulfuron 30 g/ha at 10-12 DAS, flucetosulfuron 20 g/ha at 18-20 DAS, flucetosulfuron 25 g/ha at 18-20 DAS, flucetosulfuron 30 g/ ha at 18-20 DAS, bispyribac-sodium 25 g/ha at 15 DAS, hand weeding at 20 and 40 DAS and weedy check. The treatments were replicated thrice. Short duration rice variety Kanchana (*PTB 50*) was selected as test crop which was released from Regional Agricultural Research Station, Pattambi, Kerala and the gross and net plot size were 5 x 4 m and 4.7 x 3.7 m, respectively.

Seeds were sown at 100 kg/ha after soaking in water for 24 h and keeping under shade in gunny bag for sprouting. Crop was raised based on the agronomic management practices as per Kerala Agricultural University package of practices recommendations (KAU 2011). Herbicide was applied using knapsack sprayer fitted with flood-jet nozzle. Rainy and winter crop durations were 105 and 107 days respectively. Data on rice yield attributes were recorded from 10 randomly selected plants from each plot. Productive tillers/m^2 were counted from two randomly selected sites from each plot and averaged. A random sample of spikelets were taken from the produce of each plot, 1000 spikelets were counted manually and weighed on an electronic balance. Crop was harvested and tied into bundles from the net area in respective plots, threshed, sundried and weight of grain and straw were recorded.

Data on weed dry weight was recorded at 15, 30, 45, and 60 DAS from two randomly selected quadrats (100 x 100 cm) from each experimental plot. Weeds were uprooted from ground surface, and dried in an oven at 70 ºC for determining dry weed biomass.

All the data were subjected to Analysis of Variance techniques (ANOVA) after transformation wherever needed.

RESULTS AND DISCUSSION

Weed dry weight

The weed flora in the experiment field included grasses, *viz.* *Isachne miliacea* Roth ex Roem. Et Schult, *Echinochloa colona* (L.) Link, *Echinochloa crusgalli* (L.) P. Beauv., broad-leaved weeds, *viz. Limnocharis flava* (L.) Buchenau., *Monochoria vaginalis* (Burm.f.) C. Presl ex Kunth, *Ludwigia perennis* L., *Marselia quadrifolia* L. and sedges *Schoenoplectus juncoides* (Roxb.) Palla, *Fimbristylis miliaceae* (L.) Vahl., *Cyperus iria* L., and *Cyperus haspen* L.

During rainy season at 15 DAS, flucetosulfuron 25 g/ha applied at 10-12 DAS recorded the lowest weed dry weight and was found to be on par with the highest and the lowest doses of flucetosulfuron at 10-12 DAS (**Figure 1**) while during winter season the lowest weed dry weight was recorded when flucetosulfuron 20 g/ha was applied at 10-12 DAS which remained on par with application of flucetosulfuron 20, 25 and 30 g/ha at 2-3 DAS and also with application of flucetosulfuron 25 and 30 g/ ha at 10-12 DAS (**Figure 2**). The lower weed dry weight in these treatments may be the effect of these treatments on weeds at 15 DAS. However, at 30 DAS during rainy season the highest dose of flucetosulfuron at 18-20 DAS recorded the lowest total weed dry weight and the treatments, *viz*. flucetosulfuron 30 g/ha at 10-12 DAS and flucetosulfuron 20 g/ha at 18-20 DAS were found to be comparable. Also, it was found that flucetosulfuron 25 g/ha at 10-12 DAS was on par with its application 30 g/ha at 10-12 DAS and flucetosulfuron 20 and 25 g/ha at 18-20 DAS. During winter season the lowest weed dry weight was recorded when flucetosulfuron 25 g/ha was applied at 18-20 DAS which was on par with 20 and 30 g/ha at 18-20 DAS. These were followed by flucetosulfuron 20, 25 and 30 g/ha at 10-12 DAS and application of the lowest dose of flucetosulfuron at 10-12 DAS remained on par with the same dosage at 18-20 DAS. At 45 DAS, during rainy season, hand weeding twice recorded the lowest weed dry weight followed by the application of flucetosulfuron 30 g/ha at 18-20 DAS. Whereas, during winter season the lowest weed dry weight was recorded by flucetosulfuron 20 g/ha at 18-20 DAS and was on par with 30 g/ha applied at 18-20 DAS and hand weeding twice. At 60 DAS, during rainy season, hand weeding twice recorded the lowest weed dry weight and was found to be on par with application of flucetosulfuron 20, 25 and 30 g/ha at 10-12 DAS and 18-20 DAS. During winter season also hand weeding twice recorded the lowest

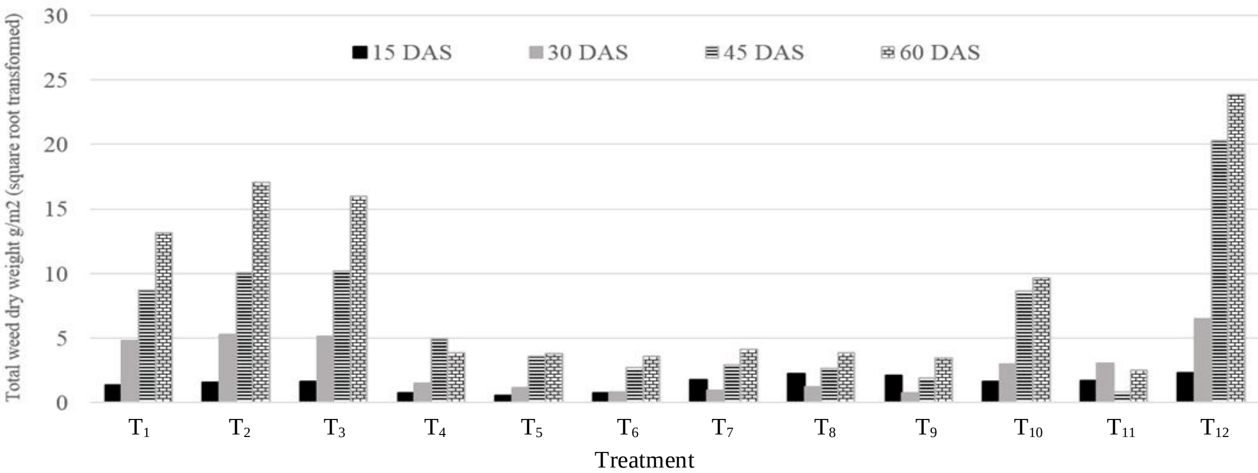
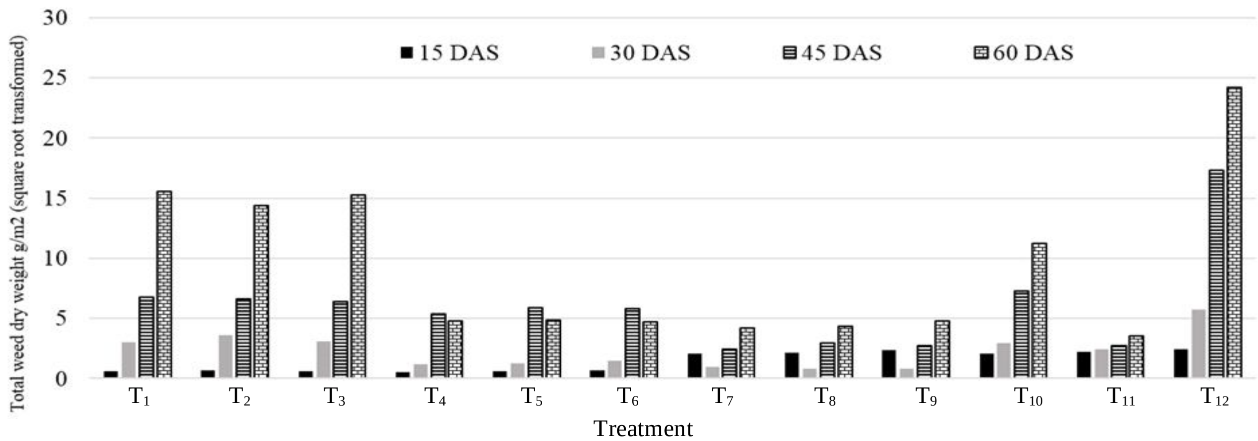


Figure 1. Effect of weed management practices on total weed dry weight during rainy season



T_1 - Flucetosulfuron 20 g/ha at 2-3 DAS; T_2 - Flucetosulfuron 25 g/ha at 2-3 DAS; T_3 - Flucetosulfuron 30 g/ha at 2-3 DAS; T_4 - Flucetosulfuron 20 g/ha at 10-12 DAS; T_5 - Flucetosulfuron 25 g/ha at 10-12 DAS; T_6 - Flucetosulfuron 30 g/ha at 10-12 DAS; T_7 - Flucetosulfuron 20 g/ha at 18-20 DAS; T_8 - Flucetosulfuron 25 g/ha at 18-20 DAS; T_9 - Flucetosulfuron 30 g/ha at 18-20 DAS; T_{10} - Bispyribac-sodium 25 g/ha at 15DAS; T_{11} - Hand weeding at 20 and 40 DAS; T_{12} - Weedy check

Figure 2. Effect of weed management practices on total weed dry weight during winter season

weed dry weight. This was followed by application of flucetosulfuron 20 and 25 g/ha at 18-20 DAS which remained on par with 20 and 30 g/ha applied at 10-12 DAS along with flucetosulfuron 30 g/ha at 18-20 DAS. Weedy check recorded significantly higher total weed dry weight for both the seasons (**Figure 1** and **2**). Similar results were reported by Bhimwal and Pandey (2014).

Here it is obvious that effect of flucetosulfuron applied at 2-3 DAS did not last for more than 15 DAS while the effect of flucetosulfuron applied at 10-12 DAS showed good weed control efficacy even in later stages. Lower weed dry weight was observed with plots where flucetosulfuron was applied at 10-12 and 18-20 DAS irrespective of dose of application, during the critical crop growth stages. Even though herbicide was applied at 10-12 DAS, those treatments could maintain a lower weed dry weight even at 60 DAS along with herbicide applied at 18-20 DAS. This may be the reason for higher grain yield in plots where the herbicide was applied at 10-12 DAS and 18-20 DAS. Herbicide treatments were effective in reducing weed biomass by more than 75% on an average (Singh *et al.* 2016). However, application of bispyribac sodium 25 g/ha at 15 DAS resulted in significantly higher weed dry weight compared to flucetosulfuron applied at 10-12 DAS and 18-20 DAS during critical stages of crop growth. This may be the reason for lower grain yield and yield attributes associated with this treatment.

Yield attributes and yield

Productive tillers/m^2 varied significantly due to the treatments (**Table 1**). During rainy season, the highest number of productive tillers was recorded by hand weeding at 20 and 40 DAS and it was on par with application of flucetosulfuron 20, 25 and 30 g/ha at 10-12 DAS and 18-20 DAS. However during winter season, flucetosulfuron 20 g/ha at 18-20 DAS recorded the highest number of productive tillers/m^2 and it was found to be on par with flucetosulfuron 20, 25 and 30 g/ha applied at 10-12 DAS and flucetosulfuron 25 and 30 g/ha applied at 18-20 DAS along with hand weeding at 20 and 40 DAS. The lowest number of productive tillers/m^2 was recorded by weedy check during both the seasons.

Flucetosulfuron 25 g/ha at 10-12 DAS recorded the highest number of spikelets/panicle (99.89) and was found to be on par with hand weeding at 20 and 40 DAS, flucetosulfuron 20 g/ha at 10-12 DAS and flucetosulfuron 25 g/ha at 18-20 DAS during rainy season while during winter season hand weeding at 20 and 40 DAS recorded the highest number of spikelets/panicle (106.78) and remained on par with flucetosulfuron 20, 25 and 30 g/ha at 10-12 DAS and 18-20 DAS. The lowest sterility percentage (12.75) was recorded by flucetosulfuron 30 g/ha at 10-12 DAS and was on par with flucetosulfuron 20 and 25 g/ha at 10-12 DAS and flucetosulfuron 20, 25 and 30 g/ha at 18-20 DAS along with hand weeding at 20 and 40 DAS during rainy season. However, during winter season, flucetosulfuron 20 g/ha at 10-12 DAS recorded the lowest percentage of spikelet sterility and was on par with all the treatments in which flucetosulfuron was applied at 10-12 and 18-20 DAS along with hand weeding at 20 and 40 DAS (**Table 1**).

Significantly higher grain yield was obtained with flucetosulfuron applied at 10-12 and 18-20 DAS along with hand weeding twice (**Table 2**). During rainy season, the highest grain yield (8.10 t/ha) was recorded by flucetosulfuron 25 g/ha at 10-12 DAS which was found to be on par with hand weeding at 20 and 40 DAS. The treatments, *viz.* flucetosulfuron 30 g/ha at 10-12 DAS, flucetosulfuron 20 g/ha at 18-20 DAS and flucetosulfuron 20 g/ha at 10-12 DAS were found to be at par with hand weeding twice. During winter season, flucetosulfuron 20 g/ha at 10-12 DAS recorded the highest grain yield (8.94 t/ha) and was at par with flucetosulfuron 25 and 30 g/ha at 10-12 DAS, flucetosulfuron 30 g/ha at 18-20 DAS and hand weeding at 20 and 40 DAS. Yield reduction due to weeds was found to be 52.33 and 55.61 per cent during rainy and winter seasons respectively. The results are in conformity with the finding of Bhimwal and Pandey (2014) who reported that flucetosulfuron 10 WG 25 g/ha applied at 2 days after transplanting recorded higher yield. Critical evaluation of the data could reveal that bispyribac sodium 25 g/ha at 15 DAS recorded significantly lower grain yield because of its poor efficacy in controlling the major weed *Schoenoplectus juncoides*.

The highest grain yield of 8.33 t/ha was recorded by flucetosulfuron 25 g/ha at 10-12 DAS and was found to be on par with hand weeding twice, and flucetosulfuron 20 g and 30 g/ha at 10-12 DAS **(Table 2)**.

Weed index and economics

Hand weeding twice recorded the lowest weed index (1.84) during rainy season, which was followed by flucetosulfuron 30 g/ha at 10-12 DAS and this was found to be on par with application of flucetosulfuron 20 g/ha at 10-12 and 18-20 DAS and flucetosulfuron 25 g/ha at 18-20 DAS (**Table 1**). During winter season, flucetosulfuron 25 g/ha at 10-12 DAS recorded the lowest weed index (4.29) and was found to be comparable with application of flucetosulfuron 30 g/ha at 10-12 DAS, flucetosul-

Table 1. Effect of weed management treatments on productive tillers/m^2, spikelets/panicle, sterility percentage, 1000 grain weight and weed index

Treatment	Productive tillers/ m^2		Spikelets /panicle		Sterility percentage (%)		1000-grain weight (g)		Weed index	
	Rainy	Winter	Rainy	Winter	Rainy	Winter	Rainy	Winter	Rainy	Winter
Flucetosulfuron 20 g/ha at 2-3 DAS	316.9	306.1	88.7	98.4	20.5	15.4	29.5	30.0	5.56 (30.45)	3.99(15.81)
Flucetosulfuron 25 g/ha at 2-3 DAS	309.7	299.2	89.9	99.2	20.7	16.6	28.9	30.4	5.81 (33.31)	4.20(17.14)
Flucetosulfuron 30 g/ha at 2-3 DAS	312.2	311.4	87.0	99.3	20.8	15.9	29.3	30.6	5.97 (35.38)	3.87(14.74)
Flucetosulfuron 20 g/ha at 10-12 DAS	435.8	451.4	98.7	103.7	14.9	10.8	29.4	31.0	3.04 (9.52)	0.701 (0)
Flucetosulfuron 25 g/ha at 10-12 DAS	450.3	416.5	99.9	103.9	13.3	12.7	29.5	30.8	0.701 (0)	1.96 (4.29)
Flucetosulfuron 30 g/ha at 10-12 DAS	450.6	415.6	95.9	106.3	12.7	12.2	29.5	31.2	2.86 (8.21)	2.08 (4.22)
Flucetosulfuron 20 g/ha at 18-20 DAS	486.1	454.4	96.2	104.3	14.9	11.8	29.5	30.8	3.03 (8.88)	2.76 (7.62)
Flucetosulfuron 25 g/ha at 18-20 DAS	433.5	433.2	97.3	104.9	15.3	12.0	29.7	30.7	3.77 (13.89)	2.91 (8.19)
Flucetosulfuron 30 g/ha at 18-20 DAS	449.1	438.1	96.6	102.3	15.1	12.5	29.2	31.0	4.04 (16.35)	2.26 (5.33)
Bispyribac sodium 25 g/ha at 15DAS	327.9	280.0	89.3	98.3	20.4	15.6	29.2	31.0	5.29 (27.66)	4.39(18.88)
Hand weeding at 20 and 40 DAS	504.8	394.9	99.6	106.8	14.3	12.9	29.6	31.4	1.50 (1.84)	2.27 (4.76)
Weedy check	294.2	267.4	80.8	91.3	24.8	21.1	28.4	30.5	7.26 (52.33)	7.50(55.61)
LSD (p=0.05)	103.2	91.5	3.3	4.4	4.20	2.2	NS	NS	1.16	1.15

Note: The data on weed index were subjected to square root transformation ($\sqrt{x+0.5}$) and the values given in parentheses are original, DAS=days after sowing

Table 2. Effect of weed management treatments on grain yield, straw yield, harvest index, net returns and B:C ratio

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Harvest index		Net returns (x10^3 `/ha)		B:C Ratio	
	Rainy	Winter	Pooled	Rainy	Winter	Pooled	Rainy	Winter	Rainy	Winter	Rainy	Winter
Flucetosulfuron 20 g/ha at 2-3 DAS	5.63	7.53	6.58	7.20	8.07	7.63	0.44	0.48	98.07	158.34	1.84	2.35
Flucetosulfuron 25 g/ha at 2-3 DAS	5.40	7.41	6.40	8.20	7.42	7.81	0.40	0.50	99.24	149.38	1.84	2.27
Flucetosulfuron 30 g/ha at 2-3 DAS	5.24	7.63	6.43	8.00	7.96	7.98	0.40	0.49	92.70	159.30	1.79	2.35
Flucetosulfuron 20 g/ha at 10-12 DAS	7.33	8.94	8.14	9.23	7.56	8.40	0.44	0.54	162.06	193.90	2.38	2.66
Flucetosulfuron 25 g/ha at 10-12 DAS	8.10	8.56	8.33	8.13	7.89	8.01	0.50	0.52	174.30	185.33	2.48	2.58
Flucetosulfuron 30 g/ha at 10-12 DAS	7.44	8.57	8.00	7.53	7.46	7.49	0.50	0.53	150.54	181.62	2.28	2.54
Flucetosulfuron 20 g/ha at 18-20 DAS	7.38	8.26	7.82	8.57	8.07	8.32	0.46	0.51	158.08	178.85	2.35	2.53
Flucetosulfuron 25 g/ha at 18-20 DAS	6.98	8.21	7.59	8.50	8.68	8.59	0.45	0.49	145.84	181.89	2.24	2.55
Flucetosulfuron 30 g/ha at 18-20 DAS	6.77	8.47	7.62	7.87	7.74	7.81	0.47	0.52	134.49	181.13	2.14	2.54
Bispyribac sodium 25 g/ha at 15DAS	5.86	7.26	6.56	9.17	8.21	8.69	0.39	0.47	119.31	150.85	2.01	2.28
Hand weeding at 20 and 40 DAS	7.95	8.52	8.23	8.90	8.18	8.54	0.47	0.51	149.32	159.53	2.03	2.10
Weedy check	3.86	3.97	3.91	7.90	7.60	7.75	0.33	0.35	59.84	60.57	1.54	1.54
LSD (p=0.05)	0.63	0.51	0.43	NS	NS	0.91	0.05	0.04	20.94	17.58	0.17	0.14

DAS=days after sowing

furon 20, 25 and 30 g/ha at 18-20 DAS along with hand weeding twice. Higher weed index was reported by weedy check during both the seasons followed by application of bispyribac sodium 25 g/ha at 15 DAS.

During rainy season, flucetosulfuron 25 g/ha at 10-12 DAS recorded the highest net returns (174.30 x10^3 `/ha) which was on par with flucetosulfuron 20 g/ha at 10-12 DAS and 18-20 DAS and these were again at par with flucetosulfuron 30 g/ha at 10-12 DAS, flucetosulfuron 25 g/ha and 30 g/ha at 18-20 DAS along with hand weeding twice (**Table 2**). During winter season, the highest net returns was recorded by flucetosulfuron 20 g/ha at 10-12 DAS and was found to be on par with flucetosulfuron 25 and 30 g/ha at 10-12 DAS and flucetosulfuron 20, 25 and 30 g/ha at 18-20 DAS. Similar results were obtained for B:C ratio also. Based on the results, it was concluded that flucetosulfuron 25 g/ha applied at 10-12 DAS effectively controlled the weeds and recorded the highest grain yield and monetary benefits in wet-seeded rice.

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Amelioration of herbicide stress with plant growth regulators and nutrients in transplanted rice

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Yield

ABSTRACT

Foliar application of two plant growth regulators (PGR)-brassinolide at 0.5 ppm, gibberellic acid at 10 ppm and one complex fertilizer NPK 19:19:19 at 1% concentration were tested alone as well as in combination with control (double dose of fenoxaprop-ethyl) and absolute control (normal dose of fenoxaprop-ethyl) against herbicide stress to rice during *Kharif* 2015 and 2016. The treatments were given 5 days after application of fenoxaprop-ethyl as foliar spray. Among the PGRs and nutrients, tank mix application of brassinolide at 0.5 ppm + NPK 19:19:19 at 1% recorded the lowest incidence of phytotoxicity (1.2) at 30 days after application and gave the highest grain yield (6.12 t/ha), net returns (` 49,431/ha) and benefit : cost ratio (1.32). Grain yield was more (5.92 to 6.12 t/ha) in brassinolide treated plot than that of gibberellic acid (5.81 to 5.83 t/ha) indicating more effectiveness of brassinolide than gibberellic acid in mitigating herbicide stress. Use of plant growth regulator and nutrient prevented 25.9% yield loss due to herbicide stress in rice.

INTRODUCTION

Biotic stress caused by improper use of herbicide is the prime factor in creating devastating tragedies in rice (*Oryza sativa* L.), which sometimes is anticipated to be incidence of unidentified disease or physiological disorder. It is increasing in current years due to wide use of herbicides without its technical knowledge of dosage, poor water management and time of application. Under severe herbicide stress due to over dosage, there might be total failure of crop. The discovery of herbicide antidotes revealed new opportunities for solving the phytotoxic effect caused by improper use of herbicide. The use of various antidotes, antagonists, protectors etc. have enabled induced crop tolerance to the specific herbicides.

Many scientific reports proposed the positive effect of plant growth regulators and nutrients on growth of stressed plant due to herbicide over dose. Brassinolides at 1 ppm can reduce the phytotoxicity of rice seedlings affected by 2,4-D and butachlor (Choi *et al.* 1990). Brassinosteroids affect the mechanical properties of cell wall during cell elongation. It is also observed from brassinosteroids deficient and insensitive mutants that brassinosteroids are essential for cell elongation and also plays role in vascular differentiation, senescence, fertility, leaf morphology and light–dark regulation development (Clouse 2011).

Gibberellins are plant hormones that participate in regulation of many growth and developmental processes in various plants (Emongor 2007) and these are especially important in regulating stem elongation (Schomburg *et al.* 2003). Role of gibberellic acid (GA) for mitigating herbicide toxicity in crop plants has been established. Treatment of *Vicia faba* with either gibberellic acid (GA_3 at 50 ppm) alone or in mixture with cytokinin reversed the phytotoxic effect of glyphosate herbicide. (Shaban *et al.* 1987). Foliar nutrient solutions containing N, P, K, Mn, Zn, B and Mo resulted in partial recovery of the negative herbicide effects on photosynthetic rate in *Zea mays*, *Triticum aestivum* and *Glycine max* under field condition (Haley 2017). The present study was designed to study the effect of brassinolide, gibberellic acid and nutrient in mitigating herbicide stress of rice plant caused due to over dosage of fenoxaprop-ethyl, a widely used new generation herbicide of this region.

MATERIALS AND METHODS

A field experiment was conducted at Regional Research and Technology Transfer Station, Chiplima, Odisha, during *Kharif* 2015 and 2016. The soil of the experimental field was sandy clay loam with pH 6.6, organic carbon 0.43% and available N ($KMnO_4$ method), P (Olsen) and K (NH_4OHC method) content of 268, 13.4 and 132 kg/ha, respectively. The experiment was laid out using randomized block design (RBD). The treatments were replicated three times. The details of treatments are absolute control fenoxaprop-ethyl at 56.2 g/ha at 20 DAT, control fenoxaprop-ethyl at 112.4 g/ha at 20 DAT, gibberellic acid at 10 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT, gibberellic acid at 10 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT, NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT, brassinolide at 0.5 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT, brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT.

Twenty five days old seedlings of variety *'MTU 1001'* were transplanted in plot size of 5 x 5 m with a spacing of 20 x 10 cm at the rate of two seedlings per hill. A common fertilizer dose of 80, 40 and 40 kg of N, P_2O_5 and K_2O/ha, respectively was applied to the crop. Full dose of P_2O_5 and K_2O and half dose of N were applied as basal and remaining N was top-dressed in 2 equal splits, at maximum tillering and panicle-initiation stages of the crop. Plant protection measures and irrigation were provided as and when required. The experiment included 7 treatments including sole and combined application of two growth regulators and one nutrient along with one absolute control, *i.e.* normal dose of fenoxaprop-ethyl and control, *i.e.* double dose of fenoxaprop-ethyl. Foliar spray of fenoxaprop-ethyl was made at 20 days after transplanting (DAT) with a knapsack sprayer fitted with flood jet nozzle. Growth hormone and nutrient were applied at 5 days after application (DAA) of fenoxaprop-ethyl after appearance of visual symptoms of herbicide stress. Crop injury was recorded on 5 and 30 DAA of herbicide by visual assessment based on 1-10 injury scale where 1 was no crop injury and 10 was complete mortality of rice plant. The recovery of crop was recorded 30 DAA of plant growth regulator and nutrient.

As a lab study, emulsion stability test was conducted. Recommended spray concentration of growth regulator and nutrient combinations were taken in a beaker and 30 ml of hard water was added and stirred with a glass rod at the rate of 4 revolutions per second. Then transferred to a 100 ml graduated cylinder and volume was made up to the mark using standard hard water. The cylinder was kept in a thermostat at 30 +/- 1 ^{0}C for 30 min. After the expiry of specified time the volume of sediment at the bottom and creamy material at the top were noted. Creamy material should not exceed ISI limit of 2 ml (Deepa and Jayakumar 2008).

RESULTS AND DISCUSSION

Laboratory study

No sediment at bottom and creamy material was found in any of the combinations. Hence it confirms that the growth hormone like brassinolide or gibberellic acid can be safely used in combination with nutrient like NPK (19:19:19).

Crop injury

Visual initial injury following double dose application of fenoxaprop-ethyl was 4 with all the treatments resulting in greater injury than fenoxaprop-ethyl applied at normal dose (**Table 1**). Foliar application of nutrient did not reverse the fenoxaprop-ethyl induced phytotoxicity in rice. Crop injury was primarily in the form of death of primary shoot and reduced overall growth of plants. Among the plant growth regulator and nutrient treatments, the maximum plant height of 66.5 cm was recorded at 30 DAA by brassinolide + NPK 19:19:19 application followed by sole- brassinolide (64.9 cm) and gibberellic acid and its combination with nutrient (56.9 to 58.1 cm). There was no significant difference in plant height of treatment receiving normal dose of herbicide absolute control fenoxaprop-ethyl at 56.2 g/ha at 20 DAT without any plant growth regulator and double dose of herbicide with plant growth regulator indicating corrective effect of PGR in neutralizing herbicide stress.

Effect on crop

The significant increase in plant height was observed in all the treatment combinations due to exogenous application of growth regulator and nutrient. Treatment brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT (112 cm) was the tallest followed by T6 (110.4 cm), which was at par with absolute control fenoxaprop-ethyl at 56.2 g/ha at 20 DAT, (113.5 cm), *i.e.* normal dose of application of fenoxaprop-ethyl herbicide. The increase in plant height is due to application of plant hormones which promoted vegetative growth by active cell division, cell enlargement and cell elongation and thus helped in

Table 1. Rice response to plant growth regulator (PGR) and nutrient (Nu) against herbicide stress (pooled data of 2015 and 2016)

Treatment	Crop injury		Plant height (cm)	
	Initial (5 DAA of herbicide)	30 DAA of PGR and Nu	Initial (5 DAA of herbicide)	30 DAA of PGR and Nu
Absolute control fenoxaprop-ethyl at 56.2 g/ha at 20 DAT	1	1	31.6	68.2
Control (fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	4	4	27.1	50.8
Gibberellic acid at 10 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	4	1.3	27.1	56.9
Gibberellic acid at 10 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	4	1.2	27.0	58.1
NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	4	2.3	27.1	55.9
Brassinolide at 0.5 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	4	1.3	27.0	64.9
Brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	4	1.2	27.1	66.5
LSD (p=0.05)				2.54

DAA – Days after application, Crop injury is measured on a Scale 1-10, 1= No crop injury and 10 = complete mortality of rice plant.

Table 2. Effect of treatments on yield attributes, yield and economics of rice (pooled data of 2015 and 2016)

Treatment	Plant height (cm)	Tillers/ m^2	Panicle Length (cm)	Spikelet/ panicle	Fertile spikelet /panicle	Test Wt. (g)	Grain yield (t/ha)	Straw yield (t/ha)	Gross returns ($x10^3$ `/ha)	Cost of cultivation ($x10^3$ `/ha)	Net return ($x10^3$ `/ha)	Benefit: cost ratio
Absolute control fenoxaprop-ethyl at 56.2 g/ha at 20 DAT	113.5	445	23.8	149	130	23.7	6.45	7.92	91.58	35.50	56.08	1.58
Control (fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	96.3	349	20.8	103	75	23.2	4.78	5.2	67.81	36.70	31.11	0.85
Gibberellic acid at 10 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	102.4	418	23.77	139	109	23.6	5.81	6.7	82.46	36.38	46.07	1.27
Gibberellic acid at 10 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	103.6	438	22.5	141	114	23.4	5.83	7.1	82.77	36.82	45.95	1.25
NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	101.4	390	23.3	122	91	23.5	4.94	6.5	70.17	36.13	34.04	0.94
Brassinolide at 0.5 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	110.4	440	23.8	146	125	23.6	5.92	7.3	84.06	37.05	47.01	1.27
Brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT	112	442	23.8	147	127	23.7	6.12	7.8	86.92	37.48	49.43	1.32
LSD (p=0.05)	3.39	106.6	NS	28.18	18.61	NS	0.66	1.85				

Input price (`/kg) rice seed, 14.1; straw, 8: urea, 5.52; di ammonium phosphate, 24.45; muriate of potash, 17.44; fenoxaprop-ethyl-ethyl 9 EC, ` 400/250 ml; brassinolide 0.1% SL, ` 135/25 ml; gibberlic acid ` 62/g; NPK 19:19:19 ` 44/kg.

improving growth characteristics and also facilitated reproductive growth (Pareek *et al.* 2000).

The effective tillers per plant are closely associated with high grain yield. A perusal of data (**Table 2**) revealed that there was significant increase in effective tillers/m^2 ranging between 390 to 442 and the highest being recorded with brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT (442) followed by T6 (440), gibberellic acid at 10 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT (438) and gibberellic acid at 10 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT (418).

Regulating total spikelets is necessary to gain high rice yields. The number of spikelet/panicle ranged from 103 to 149. All the treatment combination showed significant increase in spikelet number except only nutrient treated plot. The number of spikelets/panicle was the highest with application of brassinolide + NPK (147). More number of fertile spikelets is closely associated with higher yield/plant resulting in higher productivity. The range of fertile spikelets/panicle varied from 75 to 130. Among them, brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT (127) had highest estimate followed by brassinolide at 0.5 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT (125). Similar findings in rice were also reported by Takematsu and Takeuchi (1989).

The treatment brassinolide + NPK (brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT) gave significantly higher grain yield (6.12 t/ha) causing

28% increase of control followed by brassinolide (5.92 t/ha), gibberellic acid + NPK (5.83 t/ha and gibberellic acid (5.81 t/ha). The increase in yield with various plant growth regulators might be due to increased yield attributes, which in turn resulted from effective translocation of photosynthates. The higher yield might be due to increase in mobilization of reserve food material to the developing sink by plant growth regulator through increased hydrolyzing and oxidizing enzyme activities. (Hitoshi *et al.* 2015)

Rice yield was the highest (6.45 t/ha) in the plot of absolute control (absolute control fenoxaprop-ethyl at 56.2 g/ha at 20 DAT) without any crop injury and similar yield of 6.12 t/ha (brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT) was recorded when applied with brassinolide and nutrient (**Table 2**). No significant difference in yield between these two treatments indicates reversal of stress caused by over dose of fenoxaprop--ethyl.

Economics

Treatment without herbicide toxicity (absolute control fenoxaprop-ethyl at 56.2 g/ha at 20 DAT) registered the highest grain yield (6.45 t/ha) and monetary returns (` 56,079/ha) than sole and tank mix application of plant growth regulator and nutrient mixtures. The sole nutrient applied plot (NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT) recorded less net returns (` 34,039/ha) and benefit: cost ratio (0.94), than sole PGA applied plots but was higher than the control plot (0.85) which shows application of PGR is more effective in reducing the loss than nutrient mixture. The plant growth regulator Brassinolide in mixed application with nutrient recorded higher monetary returns than its sole application as well as all other treatments for the stressed plants (**Table 2**). Among the herbicide stressed plot (gibberellic acid at 10 ppm 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT to brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT), plant growth regulator, brassinolide + NPK 19:19:19 (brassinolide at 0.5 ppm + NPK 19:19:19 (1%) 5 DAA of fenoxaprop-ethyl at 112.4 g/ha at 20 DAT) gave the maximum net returns (` 49,431/ha) and benefit : cost ratio (1.32) followed by brassinolide alone owing to quick recovery from stress and higher grain yield as compared to other treatments.

It can be concluded that brassinolide and gibberellic acid can be safely tank mixed with NPK 19:19:19. Foliar spray of brassinolide 0.5 ppm along with 1% NPK aqueous solution can reduce the phyto toxicity caused by over-dose of fenoxaprop-ethyl in rice.

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Impact of live mulches, cover crops and herbicides on weeds and yield of direct-seeded rice

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ABSTRACT

A field investigation was conducted during the rainy seasons of 2014 and 2015 at Varanasi, Uttar Pradesh, to study the impact of live mulches, cover crops and herbicides on weeds and yield in direct-seeded rice (*Oryza sativa* L.). *Sesbania* cover crop followed by (*fb)* bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS had lesser weed density and dry weight of grasses, sedges and broad-leaved weeds than sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS. *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS had higher harvest index in comparison to sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS. *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS improved grain and straw yields with higher gross and net returns, and benefit:cost ratio as compared to sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS.

INTRODUCTION

Direct-seeded rice is becoming more popular as an alternative to transplanted rice, as it is more remunerative if the crop managed properly (Sharma *et al.* 2007). However, weeds are the main biological constraints to the production of DSR (Rao *et al.*2007, Chauhan and Johnson 2010), which may cause 60-80% reduction in grain yield of rice. Sunil *et al.* (2010) reported that season-long weed competition in direct-seeded rice may cause yield reduction up to 80%. Raj *et al.* (2013) found 72% reduction in grain yield due to the infestation of non-grassy, broad-leaved weeds and sedges in DSR. Brown manuring of green manure crops with 2,4-D significantly reduced weed population and weed dry weight compared to other incorporation method (Anitha *et al.* 2009). Singh *et al.* (2007) reported that *Sesbania* co-culture reduced broad-leaf and grass weed density by 76-83% and 20-33%, respectively, and total weed biomass by 37-80% compared with a sole rice crop. However, weeds in DSR cannot be controlled by incorporation of cover crops and live mulches alone because of multiple flushes of weeds during crop growth. The present study was taken up to assess the efficacy of herbicides along with cover crops and live mulches and to study the impact of integrated weed management on weeds and yield of DSR.

MATERIALS AND METHODS

A field experiment was conducted during the rainy seasons of 2014 and 2015 at Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. The soil was sandy clay loam, with pH 7.40, low in available organic carbon (0.41%), available nitrogen (207.47 kg/ha), and medium in available phosphorous (23.85 kg/ha) and potassium (219.60 kg/ha). The experiment was laid out in a randomized complete block design and replicated thrice, comprising 9 treatments, *viz*. *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS, sunhemp cover crop *fb* bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS, *Sesbania* cover crop *fb* *Sesbania* co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS, sunhemp cover crop *fb* sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS, *Sesbania* co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS, sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS, bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS, hand weeding at 15 and 35 DAS and weedy check during both the years. Sowing of *Sesbania* and sunhemp as cover crops was done in plots allotted to cover crop before sowing of rice manually using seed rate of 25 kg/ha 25 days before sowing of rice. Co-culture was also sown along with sowing of rice manually. In other experimental plots, rice was also sown manually using seed rate of 30 kg/

ha. In cover crops treated plot, one week after sowing of rice, cover crops were cut and placed as green mulch in between the two rows of rice. A recommended dose of fertilizer (150 kg N, 60 kg P_2O_5 and 60 kg K_2O) was applied through urea, single super phosphate and muriate of potash. Full dose of phosphorus and potassium were applied as basal application while nitrogen was applied half as basal and remaining half in two equal splits at tillering and panicle initiation stages of rice. Application of alone and tank mixed post-emergence herbicides was done as per the treatments using knapsack sprayer fitted with flat-fan nozzle. The spray volume of post-emergence herbicides was 300 L/ha. The crop was raised under irrigated condition under the recommended package of practices. Species-wise weed density and their dry weight were measured at 30, 60, 90 DAS and harvest by placing a quadrate of 0.5 x 0.5 m randomly at 2 places in each plot. These were subjected to square root transformation before analysis. Weed index (Gill and Kumar 1969) was also calculated on the basis of grain yield. Biometric characters, *viz.* yield attributes and yields (grain and straw) of rice were recorded at harvest. Prevailing price of inputs in the market during 2014 and 2015 were used to calculate the economics. The data on weeds and yields were averaged for two years before statistical analysis. LSD test (Gomez and Gomez 1984) was used for comparing treatment means.

RESULTS AND DISCUSSION

Density and dry weight of weeds

At 30, 60, 90 DAS and at harvest, *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS had significantly lower weed density of grasses as compared to rest of the treatments except hand weeding at 15 and 35 DAS and it was comparable with sunhemp cover crop *fb* bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS except at 30 DAS (**Table 1, 2 and 3**). At 30, 60, 90 DAS and at harvest, *Sesbania* cover crop *fb* bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS had significantly lower weed density of sedges and broad leaved weeds as compared to rest of the treatments except hand weeding at 15 and 35 DAS and it was comparable with sunhemp cover crop *fb* bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS. *Sesbania* cover crop *fbSesbania*co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS had lesser weed density of grasses as compared to sunhemp cover crop *fb* sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS and both treatments were statistically similar to each other except at 30 DAS. *Sesbania* cover crop *fb Sesbania* co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS had lesser weed density of sedges and broad-leaved weeds as compared to sunhemp cover crop *fb* sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS and both treatments were statistically similar to each other. This might be due to effective suppression of weeds by *Sesbania* cover crop at the time of crop emergence as it covered the soil and did not allow weed seeds to germinate along with crop. Similar hypothesis had been also proposed by Nelson *et al.*(1991) who reported that rapid development of dense ground covering by the crop suppress weeds.

Sesbania cover crop *fb* bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS recorded lower weed dry weight of grasses in comparison to sunhemp cover crop *fb* bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS and both treatments were

Table 1. Effect of weed management on grassy weed density and dry weight at different stages in direct-seeded rice (average data of two years)

Treatment	Density (no./m^2)				Dry weight (g/m^2)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Sesbania cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	2.2(4.4)	2.3(4.7)	2.3(4.7)	3.6(4.3)	1.7(2.5)	1.8(2.7)	1.8(2.9)	2.8(2.5)
Sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	2.4(5.5)	2.3(4.8)	2.3(4.8)	3.7(4.5)	1.9(3.0)	1.8(2.7)	1.9(2.9)	2.9(2.6)
Sesbania cover crop *fb Sesbania*co-culture *fb*2,4-D 0.5 kg/ha at 30 DAS	2.8(7.3)	2.3(4.9)	2.3(4.9)	4.5(6.8)	2.1(4.0)	1.8(2.7)	1.9(3.0)	3.5(3.8)
Sunhemp cover crop *fb*sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.9(7.7)	2.3(4.9)	2.3(4.9)	4.6(7.2)	2.2(4.3)	1.8(2.8)	1.9(3.0)	3.5(4.0)
*Sesbania*co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.9(8.1)	2.3(5.0)	2.3(5.0)	4.7(7.8)	2.2(4.5)	1.8(2.8)	1.9(3.0)	3.6(4.3)
Sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	3.1(9.0)	2.4(5.0)	2.4(5.0)	4.9(8.0)	2.3(4.9)	1.8(2.8)	1.9(3.1)	3.7(4.4)
Bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	2.7(6.8)	2.3(4.8)	2.3(4.8)	4.2(5.9)	2.1(3.8)	1.8(2.7)	1.9(3.0)	3.3(3.3)
Hand weeding at 15 and 35 DAS	0.7(0)	0.7(0)	0.71(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)
Weedy check	5.5(29)	5.6(31)	6.0(35)	11.0(43)	4.1(17)	5.0(24)	4.5(20)	8.2(24)
LSD (p=0.05)	0.10	0.02	0.04	3.02	0.14	0.04	0.03	2.14

Data were subjected to square root ($\sqrt{x+0.5}$) transformation; figures in parentheses are original values statistically comparable to each other except at 30 DAS. *Sesbania*co-culture *fb* 2, 4 D 0.5 kg/ha at 30 DAS had lesser weed dry weight of grasses as compared to sunhemp co-culture *fb* 2, 4 D 0.5 kg/ha at 30 DAS and both treatments were statistically similar to each other (**Table 1**). *Sesbania* cover crop *fb* bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS recorded lower weed dry weight of sedges and broad-leaved weeds in comparison to sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS and both treatments were statistically at par to each other. These findings are in conformity with the result of Khaliq *et al*. (2012). *Sesbania* co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS had lesser weed dry weight of sedges and broad-leaved weeds as compared to sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS and both treatments were statistically similar to each other (**Table 2** and **3**). The vigorous growth and better canopy coverage of live mulches suppressed the growth of weeds.

Yield attributes and yield

Weed management treatments resulted in lower weed index, which had significantly higher grain and straw yields over weedy check (**Table 4**). *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS resulted in higher number of panicle/m^2, number of grains/panicle and test weight in comparison to sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS and both treatments were statistically similar to each other. The increase in grain yield under *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS and sunhemp cover crop *fb*

Table 2. Effect of weed management on sedges weed density (no./m^2) and dry weight (g/m^2) at different stages in direct-seeded rice (average data of two years)

Treatment	Density (no./m^2)				Dry weight (g/m^2)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Sesbania cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	1.7(2.3)	1.4(1.5)	1.4(1.5)	1.6(2.2)	1.5(1.7)	1.2(1.0)	1.2(1.0)	1.4(1.6)
Sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	1.9(3.0)	1.4(1.5)	1.4(1.5)	1.7(2.6)	1.6(2.1)	1.2(1.1)	1.2(1.1)	1.5(1.8)
Sesbania cover crop *fb Sesbania*co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.1(4.1)	1.4(1.5)	1.4(1.5)	2.0(3.6)	1.8(2.9)	1.3(1.1)	1.3(1.1)	1.7(2.5)
Sunhemp cover crop *fb* sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.2(4.3)	1.4(1.6)	1.4(1.6)	2.1(4.1)	1.9(3.0)	1.3(1.1)	1.3(1.1)	1.8(2.9)
Sesbania co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.2(4.5)	1.4(1.6)	1.4(1.6)	2.0(4.2)	1.9(3.2)	1.3(1.1)	1.3(1.1)	1.9(3.0)
Sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.3(4.9)	1.5(1.6)	1.5(1.6)	2.3(4.6)	2.0(3.4)	1.3(1.1)	1.3(1.1)	1.9(3.3)
Bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	2.0(3.7)	1.4(1.5)	1.4(1.5)	1.9(3.2)	1.8(2.7)	1.3(1.1)	1.3(1.1)	1.7(2.3)
Hand weeding at 15 and 35 DAS	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)
Weedy check	3.8(14)	4.1(16)	4.9(23)	4.9(24)	3.3(10)	3.7(13)	4.1(17)	4.2(17)
LSD (p=0.05)	0.13	0.04	0.02	0.14	0.12	0.03	0.04	0.12

Data were subjected to square root ($\sqrt{x+0.5}$) transformation; figures in parentheses are original values

Table 3. Effect of weed management on broad-leaved weed density (no./m^2) and dry weight (g/m^2) at different stages in direct-seeded rice (average data of two years)

Treatment	Density (no./m^2)				Dry weight (g/m^2)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Sesbania cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	2.1(4.1)	1.7(2.4)	1.7(2.4)	2.0(3.7)	1.6(2.0)	1.3(1.3)	1.3(1.3)	1.5(1.9)
Sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	2.3(4.7)	1.7(2.5)	1.7(2.5)	2.2(4.2)	1.7(2.4)	1.3(1.3)	1.3(1.3)	1.6(2.1)
Sesbania cover crop *fb Sesbania*co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.6(6.2)	1.7(2.5)	1.7(2.5)	2.4(5.5)	2.0(3.3)	1.4(1.3)	1.4(1.3)	1.8(2.9)
Sunhemp cover crop *fb* sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.7(6.6)	1.8(2.6)	1.8(2.6)	2.5(5.9)	2.0(3.5)	1.4(1.4)	1.4(1.4)	1.9(3.1)
Sesbania co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.7(7.0)	1.8(2.6)	1.8(2.6)	2.7(6.6)	2.1(3.7)	1.4(1.4)	1.4(1.4)	2.0(3.6)
Sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	2.8(7.4)	1.8(2.)	1.8(2.7)	2.8(7.1)	2.1(3.9)	1.4(1.4)	1.4(1.4)	2.1(3.8)
Bispyribac Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	1.5(5.6)	1.7(2.5)	1.7(2.5)	2.3(4.9)	1.9(3.0)	1.4(1.3)	1.3(1.3)	1.7(2.6)
Hand weeding at 15 and 35 DAS	0.7(0.0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.71(0)	0.7(0)
Weedy check	4.5(19)	5.2(27)	5.9(34)	6.0(36)	3.3(10)	4.2(17)	4.8(22)	4.4(19)
LSD (p=0.05)	0.26	0.17	0.15	0.13	0.12	0.16	0.15	0.14

Data were subjected to square root ($\sqrt{x+0.5}$) transformation; figures in parentheses are original values

Table 4. Effect of weed management on yields, weed index, harvest index and economics of direct-seeded rice (average data of two years)

Treatment	No. of panicle $(/m^2)$	No. of grains /panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Weed index (%)	Harvest index (%)	Gross returns $(x10^3$ `/ha)	Net returns $(x10^3$ `/ha)	B:C ratio
Sesbania cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	241.8	108.6	18.8	5.0	5.9	2.4	45.7	81.8	44.2	2.2
Sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	240.8	108.0	18.8	4.7	5.7	7.8	45.2	77.4	39.8	2.0
Sesbania cover crop *fb* *Sesbania*co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	240.1	107.0	18.8	4.6	5.7	10.3	44.9	75.5	39.8	2.1
Sunhemp cover crop *fb* sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	239.8	106.5	18.7	4.6	5.6	11.4	44.7	74.6	39.0	2.0
Sesbania co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	239.5	106.0	18.7	4.5	5.6	12.3	44.8	73.8	39.6	2.1
Sunhemp co-culture *fb* 2,4-D 0.5 kg/ha at 30 DAS	239.1	102.6	18.7	4.5	5.5	13.2	44.8	73.1	38.9	2.1
Bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS	240.5	107.3	18.8	4.7	5.7	9.2	44.8	76.4	40.8	2.1
Hand Weeding at 15 and 35 DAS	250.5	111.6	20.7	5.1	6.1	0.0	45.8	83.9	37.9	1.8
Weedy check	213.3	69.3	15.9	2.3	3.3	54.6	41.6	3.8	7.4	1.2
LSD (p=0.05)	0.61	0.82	1.45	2.90	6.26	-	2.52	3.21	6.92	3.70

bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS was 115.3% and 103.4% over weedy. This could be due to the lowest weed index as compared to all other treatments except hand weeding at 15 and 35 DAS. *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS had highest harvest index in comparison to all integrated weed management treatments except hand weeding at 15 and 35 DAS. Due to effective suppression of weeds in cover crop treated plots (**Table 1, 2 and 3**) and restricting the competition by weeds for growth resources helped in improving yield and yield attributes.

Economics

The gross returns varied significantly due to different weed management treatments, which ultimately influenced the net returns and benefit: cost ratio amongst weed management treatments. *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS had higher gross returns as compared to sunhemp cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS and both treatments were statistically similar to each other. The highest net returns and benefit: cost ratio were also observed in *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS (**Table 4**). This could be attributed to higher grain yield and gross returns.

On the basis of above findings it was concluded that *Sesbania* cover crop *fb* bispyribac-Na 25 g/ha + azimsulfuron 30 g/ha at 15 DAS should be adopted for minimizing weed growth and also to obtain higher yield and monetary returns in direct-seeded rice..

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Crop establishment and weed management techniques to control in wet-rice weeds under lateritic soils of West Bengal

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ABSTRACT

A field experiment was conducted in sandy loam soil at Visva-Bharati University, Sriniketan, West Bengal in three consecutive rainy season of 2008, 2009 and 2010 to study the effect of crop establishment techniques and weed management on weed dynamics and yield of rice. Conventional transplanting method was found to be the most effective in controlling all categories of weeds throughout the growth period because of stagnation of water in the plots. Among weed management practices, pyrazosulfuron-ethyl (25 g/ha at 3 DAS/DAT) + mechanical weeding (cono-weeder) was the most effective in controlling the mixed weed flora. Similar trend was also observed in dry matter of weeds. The highest grain yield (3.75 t/ha) was obtained under system of rice intensification (SRI) with pyrazosulfuron-ethyl (25 g/ha at 3 DAS/DAT) + mechanical weeding while drum seeded with no weed control practices recorded the lowest grain yield (2.00 t/ha). SRI system with pyrazosulfuron-ethyl + mechanical weeding also gave the highest net return (` 19890/ha).

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple food crop for more than half of the world's population, including regions of high population density and rapid growth. It provides about 21 per cent of the total calorie intake of the world population. Transplanting is the most dominant and traditional method of establishment in irrigated low land rice. The area under transplanted rice in world is decreasing due to scarcity of water and labour. So, there is need to search for alternate crop establishment methods to increase the productivity of rice (Farooq *et al.* 2011). Pandey and Valesco (2005) stated that transplanted rice can be practiced in areas where low wages for labour and adequate water is available whereas direct-seeded rice can be practiced in areas with high wages and low water availability. Direct seeding reduces labour requirement, shortens the crop duration by 7-10 days and can produce as much grain yield as that of transplanted crop. It needs only 34% of the total labour requirement and saves 29% of the total cost of the transplanted crop (Ho and Romali 2000). Direct-seeding constitutes both wet- and dry-seeding and it does away with the need for seedlings, nursery preparation, uprooting of seedlings and transplanting. Irrespective of the method of rice establishment, weeds are a major impediment to rice production through their ability to compete for resources and their impact on product quality. Weed competition would be less severe under transplanting than those under direct-seeding (Singh *et al.* 2005 Savary *et al.* 2005, Rao and Nagamani 2007). Uncontrolled weeds reduced the grain yield by 75.8, 70.6 and 62.6% under dry-seeded rice (DSR), wet-seeded rice (WSR) and transplanted rice (TPR), respectively (Singh *et al.* 2005). Direct-seeding of rice allows early establishment of the succeeding crop and higher profit in areas with assured water supply by utilizing short duration modern varieties and cost efficient herbicides (Balasubramanian and Hill 2002). However, this has been accompanied by increase in weed problems and a shift in dominant grassy weeds. The innovative system of rice cultivation such as System of Rice Intensification (SRI) is being evolved to increase the productivity of irrigated rice. Under this perspective, the investigation was carried out with a view to find out the suitable crop establishment techniques along with weed management practices in rice.

MATERIALS AND METHODS

A field experiment was conducted at Visva-Bharati University, Sriniketan, West Bengal in three consecutive rainy seasons of 2008, 2009 and 2010 to study the effect of weed management and crop establishment techniques on weed dynamics and grain yield of rice. The soil of the experimental field was sandy loam in texture, porous, slightly acidic (pH 6.2), low in organic carbon and phosphorus and medium to high in available potash. The average rainfall varied from 1200 – 1400 mm of which maximum quantity is received in the month of June to October. The experiment was laid out in a split plot design with three replications involving four rice establishment techniques, *viz*. SRI, conventional transplanting, drum seeding and broadcasting in main plots and four weed management practices *viz*. pyrazosulfuron-ethyl at 25 g/ha in 3 DAS/DAT + mechanical weeding, cono- weeder at 30 DAS/DAT, two hand weeding at 30 and 45 DAS/DAT and unweeded control in sub-plots. Two types of nurseries were raised for conventional transplanting and SRI system. In conventional transplanting system, the seedlings of 25-30 days of age and in SRI system, seedlings of 12-15 days of age were transplanted. In drum seeding and direct-broad casting, pre-germinated seeds were used. For conventional transplanting, 2-3 seedlings were planted in normal spacing of 20 x 15 cm where as in case of SRI, single seedling was planted with a spacing of 25 in the soil that was muddy but not flooded. In conventionally establishment plots recommended NPK (60:30:30 kg/ha) and in SRI system, drum seeded and broadcasted system 75% of the recommended dose of fertilizer were applied. Data on weed density were recorded at 60 DAT/DAS. Yield and yield attributes were recorded as well as economics was calculated accordingly.

RESULTS AND DISCUSSION

Weed flora

The experimental rice field was infested with 23 weed species composing 5 grasses, 13 broad-leaved and 5 sedges. The weed species were *Digitaria sanguinalis, Echinochloa colona, Panicum repens, Paspalum scrobiculatum, Cynodon dactylon, Ludwigia parviflora, Hydrolea zeylanica, Lindernia ciliata, Alternanthera sessilis, Ammania baccifera, Phyllanthus simplex, Eclipta alba, Commelina nudiflora, Commelina diffusa, Spilanthes acmella, Oldenlandia corymbosa, Veronica anagallis, Gomphrena celosioides, Fimbristylis dichotoma, F. miliacea, Cyperus iria, C. haspan* and *C. difformis.* The pre-dominant weed species were *Echinochloa colona* (35% among grasses), *Fimbristylis miliacea*(50% among sedges), *Ludwigia parviflora* (30%) and *Lindernia ciliata* (25%) among the broad-leaved weeds.

Effect on weeds

Among the weed management practices pyrazosulfuron (25 g/ha at 3 DAS/DAT) + mechanical weeding significantly reduced the density and dry weight of all categories of weeds significantly as compared to weedy check. Cono weeder and twice hand weeding were more effective in controlling grassy weeds than broad-leaved and sedges (**Table 1 and 2**). Among the crop establishment techniques, conventional method of transplanting was found to be most effective in reducing the number and dry matter of weeds (11% weed density and 28% dry weight as compared to drum-seeding) and closely followed by SRI technique (8 and 9%, respectively).

Effect on yield attributes and yield

Among the establishment techniques, SRI, transplanting and broadcasting produced more effective tillers than that of drum seedling (**Table 3**). Among the weed management practices, significant results were found in number of effective tillers and grains/panicle, but there were no significant differences in test weight. Pyrazosulfuron ethyl +

Table 1. Effect of crop establishment techniques and weed control treatments on weed population in rice at 60 DAS / DAT

Treatment	No. of weeds / m^2 at 60 DAS / DAT											
	Grass			Broad-leaved			Sedge			Total		
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Rice establishment techniques												
SRI	8	7	8	54	49	46	51	49	46	113	105	100
Transplanting	5	6	6	53	51	47	48	47	45	106	104	98
Broadcasting	6	7	6	52	52	51	53	52	49	111	111	106
Drum seeding	8	9	10	57	57	51	51	52	51	116	118	112
LSD (p=0.05)	2.2	1.7	NS	2.4	5.6	2.5	3.0	NS	NS	4.8	6.5	7.3
Weed management practice												
Pyrazosulfuron 25 g/ha at 3 DAS/DAT)	2	2	2	21	21	20	24	24	22	47	47	44
Cono weeder (30 DAS/DAT)	6	6	6	58	27	52	44	45	44	108	108	102
2 HW (30 and 45 DAS/DAT	2	2	2	34	34	34	34	33	33	70	69	69
Weedy	20	19	20	104	97	89	101	98	92	225	214	201
LSD (p=0.05)	2.0	1.2	1.7	3.2	4.1	4.7	3.4	3.0	7.9	5.5	5.8	14.2

Table 2. Effect of crop establishment techniques and weed control treatments on dry matter of weeds in rice

Treatment	Dry matter (g/m^2) of weeds at 60 DAS / DAT											
	Grass			Broad-leaved			Sedge			Total		
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Rice establishment techniques												
SRI	4.2	4.1	4.3	20.7	20.3	22.5	23.5	23.1	43.4	48.5	47.6	48.0
Transplanting	3.4	3.5	3.8	20.2	18.9	19.6	13.9	14.9	15.0	38.4	37.3	38.5
Broadcasting	3.7	4.4	4.6	26.5	26.8	27.5	20.1	20.0	20.1	49.5	51.2	52.1
Drum seeding	4.9	4.7	4.9	25.4	25.5	25.5	28.1	20.6	21.1	58.4	50.7	51.5
LSD (p=0.05)	0.98	0.31	NS	1.41	1.73	2.49	0.94	1.35	4.79	3.22	1.93	5.28
Weed management practice												
Pyrazosulfuron(25g/ha at 3DAs/DAT)	0.5	0.8	0.9	9.1	8.3	8.4	5.8	5.7	5.3	15.5	14.7	14.6
Conoweeder(30 DAS/DAT)	2.5	2.5	2.7	19.1	19.0	19.9	16.4	16.0	15.6	38.9	37.5	38.2
2 HW(30 and 45 DAS/DAT	0.5	0.7	0.8	12.7	12.6	13.1	9.3	11.1	10.2	22.6	23.3	24.0
Weedy	12.7	12.7	13.3	51.8	51.5	53.6	54.0	48.0	48.6	117.7	111.2	113.3
LSD (p=0.05)	0.85	0.38	1.67	1.52	1.66	4.68	1.28	2.08	4.21	2.89	3.01	6.78

Table 3. Effect of crop establishment techniques and weed control treatments on yield attributes of rice

Treatment	No. of effective tillers/m^2			No. of grains/ panicle			Test weight (g)		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
Rice establishment techniques									
SRI	353	348	270	73	74	63	23.6	23.3	21.7
Transplanting	329	328	264	71	71	60	23.4	23.4	21.7
Broadcasting	239	310	263	71	71	58	23.5	23.4	21.7
Drum seeding	253	272	249	71	71	57	23.4	23.3	21.7
LSD (p=0.05)	6.6	6.7	7.0	NS	2.0	NS	NS	NS	NS
Weed management practice									
Pyrazosulfuron (25 g/ha at 3 DAS/DAT)	345	356	298	77	76	65	23.6	23.5	22.0
Cono weeder (30 DAS/DAT)	289	336	285	72	73	59	23.4	23.3	21.7
2 HW (30 and 45 DAS/DAT	312	316	289	76	75	62	23.6	23.4	21.8
Weedy	230	242	174	62	64	51	23.3	23.2	21.3
LSD (p=0.05)	5.2	5.4	16.0	2.4	1.1	6.0	NS	0.11	0.17

mechanical weeding produced more number of effective tillers and number of grains/ panicle. SRI, transplanting and broadcasting produced more effective tillers (25.5, 19 and 5%, respectively) than that of drum seedling rice, Among the establishment techniques.

SRI system recorded the highest grain yield of 3.30 t/ ha (**Table 4**) whereas it was the lowest in drum seeded rice (2903 kg /ha) among the rice establishment techniques. Among the weed management practices, pre-emergence application of pyrazosulfuron (25 g/ha at 3 DAS/DAT) + mechanical weeding (cono weeder) produced the highest grain yield (3.59 t /ha) and it was closely followed by HW twice (3.48 t /ha). The interaction effect was also significant. The highest grain yield (3.75 t/ha) was obtained in SRI system with pyrazosulfuron + mechanical weeding (cono weeder) followed by transplanting with pyrazosulfuron + mechanical weeding (3.71 t/ha). Higher grain yield was the resultant effect of higher yield attributes which is influenced by the reduced weed

Table 4. Effect of crop establishment techniques and weed control treatments on grain yield (kg/ha) of rice (pooled)

Weed management / Rice establishment technique	Grain yield (t/ha)				
	Pyrazo-sulfuron + mechanical	Cono weeder	HW	Weedy	Mean
SRI	3.75	3.47	3.61	2.38	3.30
Transplanting	3.71	3.52	3.64	2.24	3.28
Broadcasting	3.58	3.24	3.43	2.03	3.07
Drum seeding	3.34	3.03	3.24	2.00	2.90
Mean	3.59	3.32	3.48	2.16	
	M	W	MW		
LSD (p=0.05)	0.020	0.028	0.056		

competition. The SRI system coupled with pyrazosulfuron-ethyl + mechanical weeding reduced the total weed population and dry weight to a great extent which ultimately resulted in higher grain yield.

Economics: Among the rice establishment techniques, SRI system produced the highest net return (` 15813/ha) whereas it was the lowest in drum seeded rice (` 12,935/ha). Among the weed control treatments pyrazosulfuron-ethyl (25 g/ha at 3

Table 5. Economics of rice cultivation under different crop establishment methods and weed management (pooled)

Rice establishment technique	Weed management	Pyrazosulfuron + mechanical	Cono weeder	HW	Weedy	Mean net returns (`/ha)
SRI	Cost of cultivation (`/ha)	17600	17100	19000	15100	15813
	Gross returns (`/ha)	37490	34600	36120	23780	
	Net returns (`/ha)	19890	17560	17120	8680	
Transplanting	Cost of cultivation (`/ha)	17400	17200	18900	14900	15680
	Gross returns (`/ha)	37100	35220	36370	22430	
	Net returns (`/ha)	19700	18020	17470	7530	
Broad-casting	Cost of cultivation (`/ha)	16300	15600	17400	14500	14778
	Gross returns (`/ha)	35840	32440	34340	20290	
	Net returns (`/ha)	19540	16840	16940	5790	
Drum-seeding	Cost of cultivation (`/ha)	16500	16000	17100	14800	12935
	Gross returns (`/ha)	33360	30320	32410	20050	
	Net returns (`/ha)	16860	14320	15310	5250	
Mean net return (`/ha)		18978	16685	16710	6813	

Sale price of rice – ` 10/kg

DAS/DAT) + mechanical weeding (cono weeder) fetched the highest net return (` 18,998/ha). The highest net return ` 19,890/ha was recorded in SRI system coupled with pyrazosulfuron-ethyl + mechanical weeding whereas it was the lowest (` 5,250/ha) in drum seeding rice with no weed control treatment (**Table 5**).

The SRI system coupled with pyrazosulfuron-ethyl + mechanical weeding reduced the total weed population and dry weight to a great extent which ultimately resulted in higher grain yield and net return. Hence, SRI system integrated with pyrazosulfuron + mechanical weeding (cono weeder) may be recommended to the farmers for achieving higher yield and returns.

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Bio-efficacy of herbicides in direct-seeded rice

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ABSTRACT

A field study was conducted during summer seasons of 2015 and 2016 to evaluate the efficacy of post-emergence herbicides at Navsari Agricultural University, Navsari. Total twelve treatments consisting of pretilachlor 1250 g/ha and pyrazosulfuron-ethyl 25 g/ha as pre-emergence (PE); bispyribac-sodium salt 50 g/ha and cyhalofop-butyl 100 g/ha at 20 DAS as post-emergence; stale seedbed, hand weeding and unweeded check were evaluated. Pretilachlor 1250 g/ha PE or pyrazosulfuron-ethyl 25 g/ha *fb* bispyribac-sodium salt 50 g/ha at 30 DAS suppressed both weed density and dry weight over control. Growth and yield attributes, *viz*. plant height, no. of tillers, no. of panicles/length of panicles and no. of grain/panicles were improved significantly with pretilachlor 1250 g/ha PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS and pyrazosulfuron-ethyl 25 g/ha *fb* bispyribac-sodium salt 50 g/ha at 30 DAS. Similarly, higher rice grain and straw yields and maximum net returns were also associated with these combinations. Pre- and post-emergence application of pretilachlor 1250 g/ha or pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS appeared to be a viable strategy for weed control in direct-seeded rice with higher economic returns.

INTRODUCTION

Weed infestation in direct-seeded rice (DSR) remains the single largest constraint limiting its productivity. Recent estimates showed that average reduction in yield due to weeds varied from 12 to 72% depending upon weed flora and the extent of competition offered by weeds to the crop (Ramachandra *et al.* 2014). As the weeds and rice emerge simultaneously in DSR, the proper time and method of weed control remains a complex phenomenon. An effective early weed management tactic is imperative for any DSR production technology aiming at achieving higher productivity and profitability.

Manual weeding, although efficient in controlling weeds, has been restricted due to several economical and technological factors. Over the years, chemical weed control in DSR has emerged as promising solution of weed problem and expanded manifold as it is easy, quick, economical and feasible. Several pre-emergence herbicides applied either alone or supplemented with hand weeding have been reported to provide fairly adequate weed suppression in DSR. However, limited application time window (0-5 daysafter sowing), a critical water regimeand toxicity to main crop are associated challenges. In this scenario, post-emergence herbicides appear to offer alternate possibility. Mehta *et al.* (2010) reported good control of *Echinochloa crusgalli* with application of bispyribac-Na 30 g/ha at 30 DAS. Therefore, for complex weed flora, pre- and post-emergence herbicides combination help to target broad-spectrum weed control. Keeping above facts in view, the present study was undertaken to find out the suitable pre- and post-emergence herbicides for direct-seeded rice.

MATERIALS AND METHODS

The study was conducted at College Farm, NM College of Agriculture, Navsari Agricultural University, Navsari and Agronomic Research Farm, ASPEE Research Foundation, Mumbai. The soil pH was 7.6 and total soluble salts were 0.79 dS/m. Organic carbon, available nitrogen, phosphorus and potassium were 0.71%, 263, 46 and 412 kg/ha, respectively. A field vacated by maize crop was selected and previous field history reveals the presence of diversified weed flora of summer season.

The experiment was conducted during summers 2015 and 2016 and laid out in a randomized block design with three replications. Total twelve treatments comprising of stale seedbed by using glyphosate 1000 g/ha, pretilachlor 1250 g/ha PE, pyrazosulfuron-ethyl 25 g/ha PE, bispyribac-sodium salt 50 g/ha at 20 DAS, cyhalofop-butyl 100 g/ha at 20 DAS, pretilachlor 1250 g/ha PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS, pretilachlor 1250 g/ha PE *fb* cyhalofop-butyl 100 g/ha at 30 DAS, pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS, pyrazosulfuron ethyl 25 g/ha PE *fb* cyhalofop-butyl 100 g/ha at 30 DAS, hand weeding twice at 20 and 40 DAS, hand weeding thrice at 20, 40 and 60 DAS and unweeded check were included for comparison.

The net plot size was 5 x 3 m. The seed of rice cultivar '*NAUR-1*' was soaked in water for 6 hrs prior to sowing The rice crop was sown in the first week of July with single row hand drill, using a seed rate of 50 kg/ha and maintaining 25 cm distance between crop rows. A basal fertilizer dose of 100:30 kg NP/ha was applied. The whole phosphorus and half of nitrogen were applied at the time of sowing and remaining half nitrogen was applied in two splits at tillering and panicle initiation, respectively. In stale seedbed treatment to facilitate weed emergence, light irrigation was applied in second week of June and the first flush of weeds was controlled by application of glyphosate 1000 g/ha. Herbicides were applied using a knapsack sprayer fitted with flat-fan nozzle with spray volume of 440 l/ha.

Data on weed dynamics (density, dry biomass) was recorded at 20, 40 DAS and at harvest from two randomly selected quadrates (1 x 1 m) from each experimental unit. Weeds were clipped from ground surface, and dried in an oven at 70 ºC for 48 h for determining dry weed biomass. Data on rice yield attributes were recorded from 10 randomly selected plants taken from each net plot and computing their average. Productive tillers/m^2 were counted from two randomly selected sites from each net plot and averaged. A random sample of grain was taken from the produce of each plot, 1000 grains were counted manually and weighed on an electric balance. Treatment wise economics were calculated by considering prevailing market price as, labour: ` 178/ day, one hand weeding: ` 2136/ha, glyphosate: ` 350/ L, pretilachlor: ` 515/L, pyrazosulfuron-ethyl: ` 3000/L, bispyribac-sodium salt: ` 1600/L, cyhalofop-butyl: ` 2200/L, nitrogen (Urea): ` 13.7/kg, phosphorus (SSP): ` 46.3/kg, rice seeds: ` 30/ kg and rice straw: ` 3/kg. The data were subjected to Fisher's analysis of variance technique using "*MSTATC*" statistical software and p d" 0.05 probabilities was applied to compare the differences among treatments' means.

RESULTS AND DISCUSSION

Weed flora

The major weed flora observed in the experimental field consisted of six grass species, five of broad-leaved weeds and one sedge. The grassy weeds were *Cynodon dactylon, Echinochloa colona, Echinochloa crus-galli, Brachiaria ramosa, Eleusine indica,* and *Dactyloctenium aegyptium*. *Cyperus rotundus* was only sedge and *Boerhavia diffusa, Euphorbia hirta, Alternanthera sessilis, Trianthema portulacastrum, Digera arvensis* and *Physalis minima* were the broad-leaved weeds.

Weed density and dry weight

The data on weed density at 20 days after sowing clearly indicated that weed population in treatment of stale seed bed and pre emergence herbicide treated plots either with pretilachlor 1250 g/ ha or pyrazosulfuron-ethyl 25 g/ha was significantly lower as compared to rest of the treatments (**Table 1**). It clearly indicated that pre-emergence application of herbicides significantly reduced the total weed population during initial periods of crop growth. Pretilachlor is used in various field crops for selective control of many annual and perennial grasses while pyrazosulfuron-ethyl is effective on grasses, dicots and sedges. Similarly at 40 DAS, the lower weed density was recorded with combination of pre- and post-emergence herbicides *i.e.* pretilachlor 1250 g/ha or pyrazosulfuron-ethyl 25 g/ha supplemented with bispyribac-sodium salt 50 g/ha or cyhalofop-butyl 100 g/ha at 30 DAS but these were at par with other treatments including two and three hand weeding for sedges. However, at harvest, the lower weed population was recorded with pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS. Significantly maximum number of weeds was found under unweeded check. These results are in agreement with those reported by Singh *et al.* (2016).

Pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS, pretilachlor 1250 g/ha as PE *fb* cyhalofop-butyl 100 g/ha at 30 DAS, pyrazosulfuron-ethyl 25 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS and pyrazosulfuron-ethyl 25 g/ha as PE *fb* cyhalofop-butyl 100 g/ha at 30 DAS were found equally effective and recorded significantly lower dry weight of weeds at 40 DAS and harvest (**Table 1**). Significantly the highest dry weight of weeds was recorded inunweeded check at 40 DAS and at harvest.

Weed control efficiency and weed index

Among various weed management treatments, significantly higher weed control efficiency were recorded with pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS and pyrazosulfuron-ethyl 25 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS. Similar trend was also reported by Sunil *et al.* (2015).

Pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS emerged as best treatment to suppress the total weed flora as it recorded the lowest weed population and dry weight of weeds as well as recorded highest weed control efficiency. Hence, it was considered as base treatment to calculate weed index. Lower weed index was observed under pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS and pyrazosulfuron-ethyl 25 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS as well found most effective in controlling the weeds. However, the highest weed index and the lowest weed control efficiency was noted under unweeded check.

Crop study

Growth attributes: Plant height and number of tillers/m row length of rice at 60 DAS and at harvest were affected significantly by the different weed management treatments (**Table 2**). Significantly higher plant height and no. of tillers/m row length at 60 DAS and at harvest were recorded with application of pretilachlor 1250 kg/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS. Whereas, significantly the lowest plant height and no.of tillers/m row length was recorded under unweeded check.

Yield and yield attributes

Pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS and pyrazosulfuron-ethyl 25 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS were found equally effective and recorded significantly higher number of panicles/m row length and grains/panicle at harvest (**Table 2**). Similarly, length of panicle was also recorded higher under pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS. This could be due to the impact of effective weed control. Whereas, the lowest value of all the yield attributes was noted in unweeded check at harvest.

Significantly higher grain (2.0 and 1.9 t/ha, respectively) and straw (4.5 and 4.1 t/ha, respectively) yields were recorded in plots treated with pretilachlor 1250 g/ha or pyrazosulfuron-ethyl 25 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS (**Table 2**). The increase in grain yield under these treatments was due to the fact that the weed population and weed growth remained suppressed during crop growth period, resulting in reduced weed competition which provided better environment for proper development of growth characters, *viz.* plant height and number of tillers/m row length and yield attributes, *viz.* number of panicles/m row length, panicle length and number of grains/panicle, ultimately enhanced the grain yield of rice. Result also revealed that effective weed control in early stages of crop growth is essential for higher grain yield in summer rice crop. The result of present investigation are also in agreement with the findings supported by Sunil *et al.* (2015) and Joshi *et al.* (2015). Contrary to this, unweeded check showed the lowest grain (0.7 t/ha) and straw (1.7 t/ha) yields.

Table 1. Total weed count at 20 and 40 DAS and at harvest as influenced by weed management in direct-seeded rice (pooled data of two years)

Treatment	Total weeds no./m^2		Dry weight of weeds		Weed index %	WCE %
	40 DAS	at harvest	at 40 DAS g/m^2	at harvest kg/ha		
Stale seedbed by using glyphosate 1000 g/ha	7.3(53.0)	8.7(77.0)	59.0	935.8	47.4	48.1
Pretilachlor 1250 g/ha PE	7.5(55.7)	8.7(69.0)	61.5	926.6	47.1	48.6
Pyrazosulfuron-ethyl 25 g/ha PE	6.7(44.0)	7.9(57.3)	48.7	765.2	43.4	57.6
Bispyribac-sodium salt 50 g/ha at 20 DAS	5.3(27.3)	6.2(39.0)	33.0	479.6	38.0	73.4
Cyhalofop-butyl 100 g/ha at 20 DAS	6.2(38.0)	7.0(40.0)	42.6	601.0	47.7	66.7
Pretilachlor 1250 g/ha PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS	3.4(1067)	3.1(8.7)	11.6	110.2	-	93.9
Pretilachlor 1250 g/ha PE *fb* cyhalofop-butyl 100 g/ha at 30 DAS	3.5(11.3)	3.3(10.0)	12.9	122.8	27.9	93.2
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS	3.3(10.0)	3.4(10.3)	11.2	125.5	7.7	93.0
Pyrazosulfuron-ethyl 25 g/ha PE *fb* cyhalofop-butyl 100 g/ha at 30 DAS	3.8(1367)	3.6(12.0)	15.3	144.2	30.5	92.0
Hand weeding twice at 20 and 40 DAS	5.3(2767)	6.7(44.3)	30.5	544.9	33.5	69.8
Hand weeding twice at 20, 40 and 60 DAS	5.5(2933)	4.3(17.3)	32.0	212.0	26.4	88.2
Unweeded check	10.8(117)	12.5(156)	118.5	1802.9	64.8	0.0
LSD (p=0.05)	1.0	1.1	11.2	164.9		

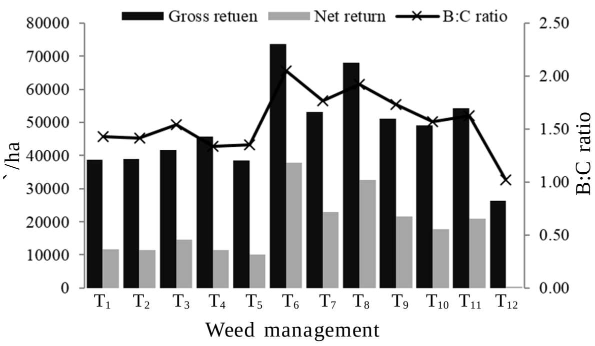
Figure in parentheses refers to original value and outside the parenthesis indicates transformed ($\sqrt{x+1}$) value

Table 2. Growth and yield attributes as influenced by weed management in direct-seeded rice (pooled data of two years)

Treatment	Plant height (cm)		No. of tillers/m^2		No. of panicles/m row length	Length of panicle (cm)	No. of grains/ panicle	Yield (t/ha)	
	60 DAS	at harvest	60 DAS	at harvest				Grain	Straw
Stale seedbed by using glyphosate 1000 g/ha	42.6	65.8	59.5	77.8	49.3	18.5	71.1	1.1	2.4
Pretilachlor 1250 g/ha PE	43.1	66.5	61.3	77.5	49.7	18.1	71.5	1.1	2.4
Pyrazosulfuron-ethyl 25 g/ha PE	42.3	69.5	61.5	78.2	51.2	19.8	74.3	1.1	2.5
Bispyribac-sodium salt 50 g/ha at 20 DAS	44.6	69.5	63.0	80.5	52.5	20.1	79.5	1.2	2.8
Cyhalofop-butyl 100 g/ha at 20 DAS	44.9	64.1	58.5	76.3	49.2	18.3	70.9	1.1	2.3
Pretilachlor 1250 kg/ha PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS	53.7	85.6	78.7	102.3	66.5	25.3	100.6	2.0	4.5
Pretilachlor 1250 g/ha PE *fb* cyhalofop-butyl 100 g/ha at 30 DAS	49.5	77.8	72.7	92.2	56.5	23.5	85.5	1.4	3.2
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS	50.8	82.7	76.7	97.5	63.8	24.3	96.5	1.9	4.1
Pyrazosulfuron-ethyl 25 g/ha PE *fb* cyhalofop-butyl 100 g/ha at 30 DAS	48.4	77.5	72.5	90.3	55.3	22.4	84.1	1.4	3.1
Hand weeding twice at 20 and 40 DAS	47.9	72.2	65.8	83.5	54.5	20.8	81.7	1.3	3.0
Hand weeding twice at 20, 40 and 60 DAS	50.6	78.7	73.5	90.2	57.2	24.1	86.3	1.5	3.3
Unweeded check	31.1	43.1	41.7	58.8	40.7	14.9	57.9	0.7	1.7
LSD (p=0.05)	8.7	12.4	11.6	17.8	8.2	3.0	12.7	0.3	0.6

Economics

Pretilachlor 1250 g/ha as PE *fb* bispyribac-sodium salt 50 g/ha at 30 DAS secured maximum net returns of ` 37770/ha with the highest B: C ratio of 2.05, which was followed by pyrazosulfuron-ethyl 25 g/ha as pre-emergence *fb* bispyribac-sodium salt 50 g/ha at 30 DAS with net returns of ` 32586/ha and B: C ratio of 1.92 (**Figure 1**). Unweeded check recorded net profit of ` 468/ha with the lowest BCR of 1.02.



T_1: Stale seedbed by using glyphosate 1000 g/ha, T_2: Pretilachlor 1250 g/ha (PE), T_3: Pyrazosulfuron-ethyl 25 g/ha (PE), T_4: Bispyribac-sodium salt 50 g/ha at 20 DAS, T_5: Cyhalofop-butyl 100 g/ha at 20 DAS, T_6: Pretilachlor 1250 g/ha (PE) *fb* bispyribac-sodium salt 50 g/ha at 30 DAS, T_7: Pretilachlor 1250 g/ha (PE) *fb* cyhalofop-butyl 100 g/ha at 30 DAS, T_8: Pyrazosulfuron-ethyl 25 g/ha (PE) *fb* bispyribac-sodium salt 50 g/ha at 30 DAS, T_9: Pyrazosulfuron-ethyl 25 g/ha (PE) *fb* cyhalofop-butyl 100 g/ha at 30 DAS, T_{10}: Hand weeding twice at 20 and 40 DAS, T_{11}: Hand weeding twice at 20, 40 and 60 DAS, T_{12}: Unweeded check

Figure 1. Economics as influenced by weed management in direct-seeded rice

Combined application of either pretilachlor 1250 g/ha or pyrazosulfuron-ethyl 25 g/ha as pre-emergence and bispyribac-sodium salt 50 g/ha at 30 DAS effectively managed weeds for achieving higher and profitable grain yield of direct-seeded rice.

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Diversity of *Echinochloa* spp. in Palakkad rice tracts of Kerala

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ABSTRACT

Surveys were conducted twice in the major rice tracts of Palakkad, once during January-February, and the other during August-September in 2016. Three major *Echinochloa* types were identified infesting rice fields, causing severe crop competition. The three types were *E. colona*, with awnless spikelets and two types of *E. crus-galli*, *viz. E. crus-galli* (type A) having short awns and *E. crus-galli* (type B) having long awns. Other than the length and arrangement of awns, there were no significant differences in the morphological characters of the latter two types. Frequency and relative frequency was the highest for *E. crus-galli* (type B). There was no specific association between the *Echinochloa* types and soil nutrient parameters, probably as there were no drastic differences in the chemical properties among the different locations. Cluster analysis classified *Echinochloa* types in to 5 groups at 66.67% similarity level. The study concludes that in a less productive environment, the awned types of *Echinochloa* could have a better chance of survival.

INTRODUCTION

The most important biological constraint to rice production is weed infestation. Effective weed management plays an important role in rice cultivation to prevent yield loss, reduce production cost and ensure grain quality. Weed infestation causes 9-51% yield reduction in rice crop (Mani *et al.* 1968). The yield reduction due to weed infestation and expense of weed management together contribute an estimated 15% loss in rice production (Smith 1981). *Echinochloa* species are one of the most destructive weeds associated with rice crop, distributed throughout the world especially in tropical and warm-temperate regions (Michael 2003, Shultana *et al.* 2013). Severe infestation of *Echinochloa* spp. has been reported in wet seeded rice in 15 countries, and in dry seeded rice in 22 countries and also in transplanted rice (Chauhan and Johnson 2009).The genus has more than 50 species, which includes the third and fourth most important weeds in the world, *viz. Echinochloa crus-galli* (L.) and *Echinochloa colona* (L.) (Holm *et al.* 1977, Michael 2003). Weeds belonging to *Echinochloa* species vary in their growth habit, distribution, and morphology (Barret and Wilson 1983). Being C_4 plants, *Echinochloa* are adapted to diverse environmental conditions. Their adaptations include the ability to flower in varying photoperiods and to produce numerous seeds, which are easily dispersed. The seedlings of *Echinochloa* closely resemble rice seedlings, and sometimes they are unintentionally transplanted to rice fields or might escape from hand weeding (Rao and Moody 1988). They are very strong competitors with rice and can cause drastic reduction in rice yield (Rao and Moody 1992).

India is one of the largest producers of rice in the world, having an area of 43.49 mha under rice cultivation with an annual production of 104 mt. Kerala is an Indian state located at the south western end of Indian peninsula at latitudes between 8°18' and 12°48' N longitudes between 74°52' and 77°22'E. The warm humid tropical climate and ample rainfall ensure the suitability of rice cultivation in the state. Palakkad, '*Kuttanad*', '*Pokkali*', '*Kole*' lands and 'Kaippad' are the main rice growing tracts of Kerala. Palakkad district, known as the granary of Kerala, has the largest acreage of rice cultivation in the state and contributes more than 45% of the total rice produced. Recently, some new types and unidentified species of *Echinochloa* have been seen to occur in the rice fields of Kerala, especially in Palakkad district. These are believed to have been brought to the area through contaminated seeds and through mechanical harvesters, which were previously used in other states, or may be due to introgression of the existing *Echinochloa* types. Variation in genetic and morphological characters of *Echinochloa* spp. may also be associated to differential response to herbicides (Altop and Mennan 2011). The new species or morphotypes are reported to be tolerant or less sensitive to conventional herbicides. It is essential to properly identify the new species and ecotypes based on important morphological traits for selecting the appropriate herbicides to be used effectively against each type. In this context, the objective of the present investigation was to study the diversity of *Echinochloa* spp. in the rice fields of Palakkad based on morphological characters.

MATERIALS AND METHODS

The study was focused on the rice tracts of Palakkad district in Kerala located between the latitudes of 10Ú21' to 11Ú14' North, and longitudes of 76Ú02' to 76Ú45' East. Stratified surveys were conducted twice, the first one in the months of January and February, and the second in August and September of 2016 in key rice growing areas of Palakkad rice tracts. Eleven locations were identified where different species or types of *Echinochloa* dominated. From each location, important morphological observations were recorded on 50 plants during the flowering stage. Observations on soil chemical properties, water management and weed management were also recorded. Seeds of different species and types were collected. Panicles of *Echinochloa* types collected in surveys were identified at the Botanical Survey of India, Southern Regional Centre, TNAU Campus, Coimbatore, India. Morphological studies of each type of *Echinochloa* were conducted as pot culture study at College of Horticulture, Kerala Agricultural University, Thrissur.

Observations such as plant height, number of tillers/ plant, number of panicles per plant, growth form, leaf arrangement and size, flag leaf size, dry matter production/plant, presence or absence of awns and panicle characters were recorded from the field. Soil chemical properties (pH, organic C, available N, P and K) and moisture status in the field were also recorded. The degree of abundance of each species/ morphotype of *Echinochloa* was noted in terms of frequency and relative frequency.

The observations recorded in lab and pot culture studies were as follows:

$$\text{Weed frequency} = \frac{\text{Number of sites where a particular weed species occurred}}{\text{Total number of sites surveyed}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species}}{\text{Total number of frequencies of all species}} \times 100$$

Germination percentage: Germination studies on each type of *Echinochloa* were conducted in the laboratory. Seeds showing dormancy were subjected to pre-treatment with ethanol (1. M) under darkness for 3 days. For germination test, 10 seeds each were placed in petri dishes of 9 cm diameter lined with a piece of Whatman No.1 filter paper which had been moistened with distilled water. Seeds with a visible protrusion of radicle were considered to have germinated. The number of germinated seeds was counted at 15 days after sowing or until there was no further germination.

Time to emergence: In pot culture, the time required for the shoot to reach the soil surface was recorded and indicated in days.

Heading time: The duration required for the panicle to become fully visible was recorded and indicated in days.

Growth duration: The duration from germination to final drying of plants was recorded and indicated in days.

Observations on the nine quantitative morphological characters recorded at the survey locations were subjected to cluster analysis using Euclidean distance as a similarity index. The associated dendrogram was obtained using the statistical package ‘Minitab Version 17’. PCA was also performed in the same statistical package with the same quantitative morphological observations to find the contribution of the observed characters in grouping of the *Echinochloa* types.

RESULTS AND DISCUSSION

The serious problem of *Echinochloa* in Palakkad rice tract is aggravated by the appearance of a number of morphotypes or biotypes. Biotypes are plants showing a random genetic variant within an ecotype (Klingman and Oliver 1994). Fifteen types of *Echinochloa* were obtained from 11 survey locations in Palakkad (**Table 1, Figure 1**). Plant morphology under uniform conditions can be influenced by environmental conditions and plant genotype. It is reported that the morphological characters of *E. crus-galli* are affected by soil type and fertility level (Martines *et al.* 1999). Most species of *Echinochloa* are highly polymorphic and variable in the characteristics usually considered, and are difficult to distinguish (Michael 1983).

Table 1. Distribution of *Echinochloa* spp./morphotypes in rice fields of surveyed areas

Location	Latitude (^{0}N)	Longitude (^{0}E)	*Echinochloa* species/ morphotypes	Code no. of *Echinochloa* types
Chithali 1	10°41'25.9"	76°34'58.6"	*Echinochloa colona*	1
Chithali 2	10°41'23.2"	76°34'59.3"	*Echinochloa crus-galli*(type A)	2
			Echinochloa crus-galli(typeB)	3
Parakkattukavu	10°39'19.0"	76°31'11.2"	*Echinochloa crus-galli*(typeB)	4
			Echinochloa colona	5
Modappallur	10°35'27.9"	76°31'02.4"	*Echinochloa colona*	6
Kozhinjampara	10°44'29.5"	76°49'48.8"	*Echinochloa crus-galli* (type A)	7
Thathamangalam	10°40'43.2"	76°42'35.9"	*Echinochloa crus-galli* (type A)	8
Koduvayur	10°40'25.7"	76°38'36.2"	*Echinochloa crus-galli* (type B)	9
Thrippalur	10°38'54.3"	76°33'56.5"	*Echinochloa colona*	10
Kunissery	10°38'19.8"	76°35'27.5"	*Echinochloa crus-galli* (type B)	11
Cheramangalam	10°37'14.1"	76°35'15.1"	*Echinochloa crus-galli* (type A)	12
			Echinochloa crus-galli (type B)	13
Ayilur	10°34'49.5"	76°34'11.5"	*Echinochloa crus-galli* (type A)	14
			Echinochloa crus-galli (type B)	15

From the survey conducted in the major rice producing tracts of Palakkad district, three major *Echinochloa* types were obtained, and they were identified at Botanical Survey of India, Southern Regional Centre located at TNAU Campus, Coimbatore, India. The three types included *E. colona* (synonym: *Panicum colonum* L.) and two types of *E. crus-galli*, one with short awns designated as *Echinochloa crus-galli* (type A) (Synonym: *Panicum crus-galli* L.) and the other with longer awns named *E. crus-galli* (type B) (*Panicum crus-galli* L., *Echinochloa glabrescens* Munro ex Eggel. or *Echinochloa oryzoides* auctnon (Ard.) Fritsch). The nomenclature *E. colona* was adopted in favour of *E. colonum* as per the conclusion reached by Michael (2009). The frequency of distribution and relative frequency of *Echinochloa* was the highest for *E. crus-galli* (type B) followed by *E. crus- galli* (type A) and *E. colona* (**Table 2**).

The two types of *Echinochloa crus-galli* were distinctly different with respect to awn length and arrangement of awns on the spikelets. In fact, the type collected and named as *Echinochloa crus-galli* (type A) had earlier been identified as *E. glabrescens* (Thomas and Abraham 1998, 2007). In *E. crus-galli* (type A), the spikelets were broadly ovate to ovate with short awns up to 1.5 mm long. The awns were abundant and either scattered throughout the panicle or confined on the spikelets at the tip of the panicle branches. In *E.crus-galli* (type B), the spikelets were ovate with long awns distributed throughout the panicle. The length of awn went up to 11 mm. *E. colona*, on the other hand, was awnless. There were no other significant differences in the morphological characters recorded of *E. colona* and *E. crus-galli* types. The major morphological characters of the three types of *Echinochloa* are presented in **Table 3**.

Table 2. Frequency and relative frequency of *Echinochloa* species/morphotypes in rice fields of surveyed areas of Palakkad

Echinochloa species/ Morphotype	Frequency (%)	Relative frequency (%)
Echinochloa colona	36.36	23.53
Echinochloa crus-galli (type A)	54.54	35.29
Echinochloa crus-galli (type B)	63.64	41.18

Table 3. Morphological characters of *Echinochloa* spp. and types

Parameter	*Echinochloa colona*	*E. crus-galli* (Type A)	*E. crus-galli* (Type B)
Duration (days)	95-120	90-120	>120
Days to germination	3-5	3-7	2-4
Days to heading	60-75	50-60	70-95
Plant habit	Erect	Erect	Erect
Height of plant (cm)	53-186	76-195	46-194
No. of tillers/plant	1-17	1-21	1-9
No. of panicles/plant	1-18	1-21	1-9
Stem colour	Greenish	Greenish	Greenish
Culm nature	Erect, ascending	Erect, ascending	Erect, ascending
Leaf colour	Light green	Light green	Light green
Leaf arrangement	Alternate-opposite	Alternate-opposite	Alternate-opposite
Length of leaf (cm)	38.8	20.4	22.5
Width of leaf (cm)	1.09	0.8	0.8-1.5
Dry smatter production, g/plant	5.32-7.68	1.5	4.86-7.84
Panicle length (cm)	10-40	4.98-7.93	25-45
Panicle arrangement	Loose/ compact	Compact	Loose to tight
No. of branches/panicle	17	18.7	18
No. of spikelets/panicle	371	487	403
Seed production/plant	1447	1682	766
Spikelet colour	Greenish/ purplish	Purplish/ green	Green to purple
Awns present/absent	Absent	Present	Present
Length of awn (mm)	-	1.50	6-13.5
Length of spikelets (mm)	3.45	4.70	14.75
Width of spikelets (mm)	1.60	1.75	1.9

Cluster analysis classified *Echinochloa* types in to 5 groups at 66.67% similarity level. Group 1 included two types, *i.e*. type 1 and 14. Type 2 occupied as a separate group (group 2). Group 3 included 7 types, *i.e*., types 3, 8, 7, 9, 12, 10, and 13. Group 4 had 3 types, *i.e*., 6, 11 and 15. Two types (type 4 and 5) occupied group 5 (**Figure 2**).

The scree plot of PCA revealed that first 3 principle components correspond to the whole percentage variance in the data as they have Eigen value greater than 1 (**Figure 3**). PC1, PC2 and PC3 together accounted for 76.9% of the total variations, of which PC1 accounted for 34.4%, PC2 for 28.3% and PC3 for 14.2% variation. The first PC was related to all the morphological observations taken and the second PC related to all morphological observations except leaf length, leaf width, and dry weight. PC3 was related to the factors number of tillers/ plant, number of panicles/ plant and dry weight. PC1 was more positively contributed to by the characters in the order of plant height, leaf width, panicle length, dry weight, flag leaf width, number of panicles plant, leaf length, flag leaf length and number of tillers/ plant. PC2 was more positively contributed to by number of tillers/ plant, flag leaf length, number of panicles per plant, flag leaf width, plant height and panicle length (**Table 3**).

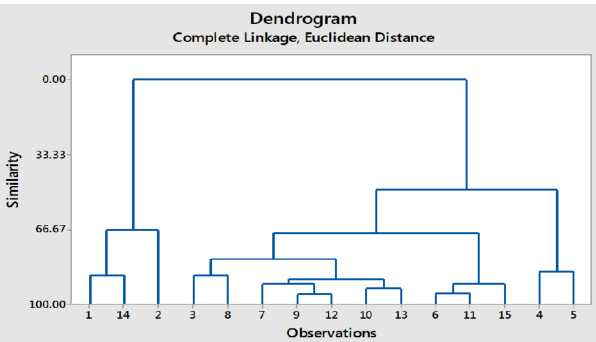

Figure 2. Dendrogram from hierarchial cluster analysis for dissimilarity among the 15 morphotypes of *Echinochloa* spp.

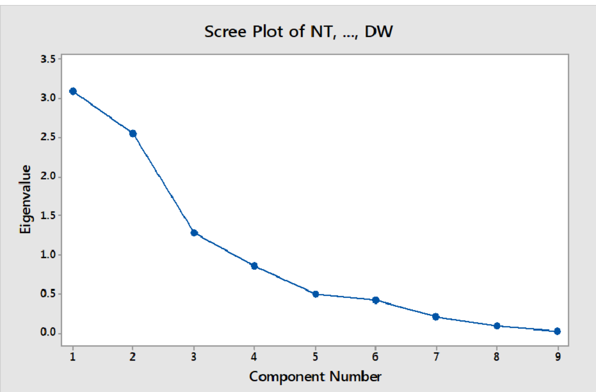

Figure3. Scree plot showing the Eigen values in response to the quantitative morphological characters of *Echinochloa* spp.

The scree plot between PC1 and PC2, which together contributed more than 60% variability, showed that the *Echinochloa* types included in different groups had different morphological characters. Many of the types coming under group 3 were distributed farther from each other, pointing to wide variation between the individuals of the group. The individuals of group 2 were distributed farther from other groups, indicating large variation from the other types (**Figure 4**).

Soil chemical properties and moisture level in the field

Semi-dry system of rice cultivation was followed throughout the survey locations in Palakkad rice tract, with saturated soil conditions. *Echinochloa* types were abundant in acidic to neutral pH prevailing in the area. Severe infestation of *Echinochloa* complex was observed in soils with high organic carbon, moderate nitrogen and phosphorus, and low to high potassium (**Table 4**). There was no specific association between *Echinochloa* types and soil nutrient parameters, probably as there were no drastic differences in chemical properties between

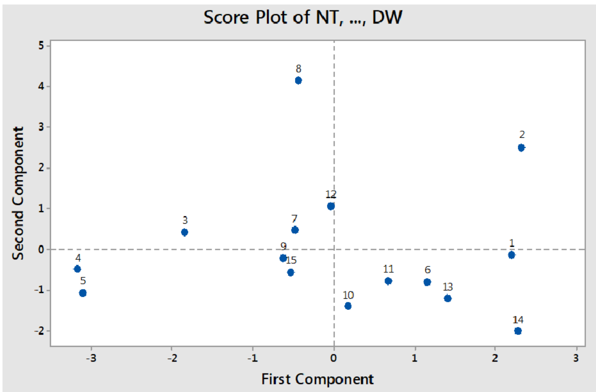

Figure4. Scree plot of first two PC indicating the variability in morphological characters of *Echinochloa* spp.

Table 4. PCA values of quantitative morphological characters of *Echinochloa* spp.

Morphological observations	PC1	PC2	PC3
No. of tillers/ plant (NT)	0.132	0.552	0.196
No. of panicles/ plant (NP)	0.274	0.256	0.543
Plant height (PH)	0.485	0.042	-0.019
Leaf length (LL)	0.260	-0.441	-0.230
Leaf width (LW)	0.403	-0.329	-0.135
Flag leaf length (FLL)	0.145	0.484	-0.404
Flag leaf width (FLW)	0.340	0.226	-0.478
Panicle length (PL)	0.400	0.032	-0.004
Dry weight (DW)	0.382	-0.198	0.451
Eigen value	3.0989	2.5474	1.2742
Proportion	0.344	0.283	0.142
Cumulative	0.344	0.627	0.769

Table 5. Soil chemical properties and moisture level in rice fields of different locations

Location	Soil pH	Organic C (%)	Available N (kg/ ha)	Available P (kg/ ha)	Available K (kg/ ha)	Soil moisture level
Chithali 1	4.41	0.76	501.76	20.00	142.20	Saturated
Chithali 2	4.46	0.80	627.20	32.17	84.00	Saturated
Parakkattukavu	6.41	0.74	376.30	17.96	142.24	Saturated
Modappallur	4.74	0.93	689.90	12.95	152.30	Saturated
Kozhinjampara	7.76	1.17	439.04	03.34	84.00	Saturated
Thathamangalam	6.28	0.62	627.20	23.40	227.33	Saturated
Koduvayur	6.49	0.78	439.04	12.53	108.60	Saturated
Thrippalur	6.02	0.81	376.02	10.03	67.20	Saturated
Kunissery	5.40	0.77	439.04	21.31	99.68	Saturated
Cheramangalam	4.85	0.87	376.00	44.29	113.12	Saturated
Ayilur	6.00	0.71	439.04	130.80	381.92	Saturated

different locations. The rice fields of Palakkad district covered in the survey had similar soil properties leading to infestation by all the three types of *Echinochloa* throughout. *E.crus-galli* (type B) recorded a slightly higher relative frequency than *E.crus-galli* (type A), pointing to a better adaptability to the existing conditions.

E. crus- galli and *E. colona* are thus the two species of *Echinochloa* identified in the rice tracts of Palakkad district. However, the presence of two types of *E. crus- galli* is a cause for concern, indicating the development of morphotypes in response to the existing environment and cultural practices used by farmers. The presence of long awns in *Echinochloa crus-galli* (type B) could be an adaptation to reduce grain number so as to increase grain size, thereby increasing probability of survival. In wheat, Rebetzke *et al.* (2016) found that awns are coupled with larger grain size and yield in less favourable environments, but reduce grain number in more favourable environments. Palakkad soils are acidic in reaction and the region is prone to drought. In such a less productive environment, the awned types of *Echinochloa* could have a better chance of survival. Such evolutionary developments could cause considerable difficulty in controlling the weed and increase the potential risk of rice cultivation in such areas.

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Effect of crop establishment and weed management practices on growth and yield of wheat

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ABSTRACT

A field experiment was conducted during the winter season of 2012-13 and 2013-14 at ICAR-DWR, Jabalpur, Madhya Pradesh, to study the effect of crop establishment and weed management practices on growth and yield of wheat. Maximum reduction in density and biomass of *Phalaris minor* and *Avena ludoviciana* was recorded under zero-tillage with residue while in *Medicago denticulata* under conventional tillage practices. Zero tillage with residue retention recorded higher grain and straw yield as well as net return and B:C ratio. Among the different herbicides ready mix application of sulfosulfuron + metsulfuron (32 g/ha) significantly reduced weed density and dry biomass accumulation, and which was followed by application of mesosulfuron +iodosulfuron and mertibuzin over weedy check due to enhanced of growth, yield and benefit cost ratio of wheat. As compared to weedy, the higher yield attribute character and yield of wheat was produced with the herbicidal treatments. The maximum yield, net return and B:C was achieved with the post-emergence application of sulfosulfuron + metsulfuron.

INTRODUCTION

Introduction of high yielding dwarf genotypes, improved fertilizer and irrigation facilities coupled with scientific research have led India to the prestigious position in the world in wheat production (92.29 million tonns in 2015-16). There are many factors affect the yield of wheat but weed infestation is one of the most serious causes of low yield of irrigated wheat due to severe competition between weeds and crop plants for moisture, nutrient, light and space. The studies of Brar and Walia (2008) revealed that severe competition of grassy weeds like *Phalaris minor* caused 30-80% reduction in grain yield of wheat. The most common methods used by farmers for weed management are tillage system, crop rotation and herbicide application (Ball 1992). Tillage plays an important role in controlling weeds and managing crop residues. Herbicides are more effective in controlling the weeds besides reducing the total energy requirement for wheat cultivation. Systematic comparison of weed infestation, and wheat yield in conventional tillage, zero tillage without residue, zero tillage with residue and zero tillage with residue burning are not yet well understood. We hypothesized that modifications and innovations of agricultural technologies, such as land preparation operations, establishment methods, and weed control methods, have different effects on weed flora composition and wheat productivity. Therefore, a study was conducted at the DWR, research farm to evaluate the effect of different wheat establishment methods and weed control treatments on weed emergence, weed growth, and wheat yield.

MATERIALS AND METHODS

A field experiment was conducted on Vertisol (medium to deep depth and black in colour) clayey in texture soil of ICAR-Directorate of Weed Research, Jabalpur, MP (23º132 N and 79º592 E with an altitude of 388 m above the mean sea level) during 2012-13 and 2013-14 to evaluate the performance of different tillage and weed management practices on growth and yield of wheat. The soil was medium in organic carbon (0.79%), available nitrogen (312 kg/ha), phosphorus (18 kg/ha), potassium (291 kg/ha) and having pH 7.2. The experiment was conducted in split-plot design having 4 tillage practices *viz*. conventional tillage , zero tillage without residue, zero tillage with residue and zero tillage with residue burning were taken in main plots, while weed management treatment in sub plots. The conventional tillage was performed by cultivator and planking. In zero tillage, T-type slit/furrows were opened at a spacing of 20 cm for wheat with the help of happy seeder and sowing of seed and fertilizers was done in furrows. Four weed management treatments, *viz*. ready mixed combination of herbicides, *viz*. mesosulfuron + iodosulfuron (12+2.4 g/ha), sulfosulfuron + metsulfuron (32 g/ha), metribuzin (200 g/ha) and weedy check were included in the experiment. The treatment was replicated three. The variety of wheat was '*GW 273*'. Recommended dose of fertilizers (120 kg N + 60 kg P_2O_5 + 40 kg K_2O) were applied in wheat. Half dose of nitrogen and full dose of phosphorus and potash were applied at the time of seeding. The remaining nitrogen was top dressed in two equal splits, at the time of first and second irrigation. Herbicides were sprayed by knapsack sprayer fitted with flat-fan nozzle using a spray volume of 500 L/ha at 30 days after sowing (DAS). Weedy check plots remained infested with native population of weeds till harvest. Observation on weed density and dry matter accumulation were recorded from 4 random quadrate of 0.5 × 0.5 m in each plot at 20 days after herbicide application. Total number of weeds falling within each quadrate were counted and cut at ground level for measuring weed dry weight data. The sample were first dried in sun and after then kept in oven at 65°C. The dried samples were weighted and expressed in g/m^2.Data on weeds were subjected to square-roots transformation $\sqrt{(x + 0.5)}$ to normalize their distribution. Leaf area index (LAI) is defined as the area of leaves per unit area of soil surface. LAI was quantified with the Accu PAR model LAI-2200 C, Inc. instrument, which calculates LAI based on the above and below-canopy PAR measurements. For root volume studies, the soil saturated with water before uprooting the wheat plant from experimental plots to avoid losses of root tissues. After uprooting the plant with soil it was kept overnight in large buckets and shacked gently to remove soil and other foreign material. Once, the soil is removed from roots it was washed again with fresh water. The root volume measurement was made using water displacement. To determine the yield of wheat, an area of 10 m^2 each sub plot was harvested by manually after physiological maturity, tied into bundles, sun dried and weight of bundle was recorded with the help of digital balance in kg. The biomass of each sub plot was threshed, cleaned and grain yield was recorded in kg/plot. The Grain yield recorded in kg/plot was finally converted into grain yield kg/ha. The statistical analysis of data was done using SAS Windows Version 9.3.

RESULTS AND DISCUSSION

Weeds

The dominant weed species identified in the experiment field of wheat ware *P. minor, A. ludoviciana* and *M. denticulata*. The higher density and biomass of *P. minor* and *A. ludoviciana* were observed under convention tillage in wheat while *M. denticulate* was higher in Zero-tillage with residue because of soil disturbance by tillage practices may have brought the deep buried weed seeds near to soil surface, where, provide favorable environment *i.e*. light, oxygen and moisture for facilitated the germination and emergences of weed seeds (**Table 1**). Choker *et al.* (2009) observed that density of *P. minor* was higher under conventional tillage. But, infestation of broad- leaved weed *Rumex dentatus* and *M. denticulata* was maximum under zero-tillage condition. The significantly lower density and biomass of all weeds under zero- tillage with residue of rice in wheat was owing to deeper buried of weeds seeds. Beside, statistical analysis revealed significantly difference between weed management practices. Application of ready mixture of sulfosulfuron + metsulfuron was recorded more effective in controlling grasses and broad leave weeds followed by mesosulfuron + iodosulfuron as compare to metribuzin while highly infestation of weeds was found under weedy check over rest of the treatments. Similar result was also recorded by Yadav and Dixit (2014). The total weed density and dry matter accumulation of weeds varied significantly under different tillage practices in wheat. Minimum weed density and dry matter were recorded form zero-tillage with residue plots, which was statistically at par with zero-tillage with residue burning. As compared to conventional tillage, the significantly lower weed density and dry weight was recorded from zero tillage practices. In case of zero tillage with rice residue, the lower weed emergence and growth was observed; and it may be due to rice residue on the soil surface that reduce light transmittance and release allelopathic compounds. Similar results were found as by Yenish (1995) and Chhokar *et al.* (2007). The lower density and dry weight of weed in zero-tillage was due to lesser emergence owing to higher soil strength. Soil strength was higher up to zero-tillage, moisture remain higher than conventional tillage. In conventional tillage the upper layer soil layers dry very fast leading to lesser moisture and ultimately lesser weed emergence before first irrigation. Chhokar *et al*. (2007) also reported the similar observation.

Statistical analysis revealed significantly difference between weed management practices. As compared to other herbicides, application of sulfosulfuron + metsulfuron significantly reduced the density and dry weight of weed, which was closely followed by mesosulfuron + iodosulfuron and metribuzin. However, the post-emergence application of sulfosulfuron + metsulfuron, mesosulfuron+ iodosulfuron and metribuzin curtailed the density and dry weight of both the grassy and broad leaved weeds, although an inflated control of weeds were observed with the application of ready mix herbicide formulation. Good performance of sulfosulfuron + metsulfuron-methyl in the present study is also supported by the results of Zand *et al.* (2007). The maximum weed control efficiency was recorded in sulfosulfuron + metsulfuron over rest of the treatments. Similar result was also recorded by Yadav and Dixit (2014).

The growth parameters, *viz.* plant height, number of tiller, dry matter accumulation and leaf area index differed significantly due to tillage practices (**Table 2**). The tallest plant with the maximum number of tiller/m^2 were observed with zero-tillage with residue retention practices and it was closely followed by zero–tillage with residue burning. Similar trend was also found in case of all other growth parameters i.e dry matter accumulation and leaf area index. Rice residue retained under zero-tillage improved plant growth due to nitrogen mineralization, increased moisture availability, reduced weeds competition and increased photosynthesis rate (Kumar *et al.* 2016). Root volume did not differ significantly with various tillage practices.

The data showed that of growth parameter, *viz.* plant height, number of tiller/m^2, leaf area index and dry matter accumulation significantly varied with different weed management practices. The lowest values of all plant growth parameter were observed with unweeded situation, whereas, plots receiving post emergence herbicides, *viz.* sulfosulfuron + metsulfuron, mesosulfuron + iodosulfuron and metribuzin recorded higher crop growth rate. These

Table 1. Effect of crop establishment and weed management practices on weed density and dry biomass accumulation and weed control efficiency in wheat (pooled data of two years)

Treatment	Weed density (no./m^2)				Weed dry weight (g/m^2)				Weed control efficiency (%)
	P. minor	*A. ludoviciana*	*M. denticulata*	Total	*P. minor*	*A. ludoviciana*	*M. denticulata*	Total	
Tillage practices									
Conventional tillage	8.91(79)	6.49(42)	4.11(16)	12.14(147)	2.74(7.0)	1.89(3.1)	2.88(7.8)	4.33(18)	-
Zero-tillage without residue	8.35(69)	5.48(29)	3.55(12)	11.46(131)	1.80(2.7)	1.75(2.6)	2.59(6.2)	3.57(12)	-
Zero-tillage with residue	7.47(55)	6.85(46)	3.31(10)	10.94(119)	1.71(2.4)	2.07(3.8)	2.36(5.1)	3.52(12)	-
Zero-tillage with residue burning	8.48(71)	5.91(34)	3.50(12)	11.32(128)	1.72(2.5)	1.79(2.7)	2.60(6.3)	3.49(12)	-
LSD (p=0.05)	0.30	0.90	0.16	0.14	0.21	0.09	0.15	0.09	-
Weed management practices									
Mesosulfuron+iodosulfuron (12+2.4 g/ha)	6.94(48)	4.93(24)	2.49(6)	7.18(79)	1.48(1.7)	1.47(1.7)	1.92(3.2)	2.68(6.7)	79.0
Sulfosulfuron+metsulfuron (32 g/ha)	5.87(34)	4.21(17)	2.57(6)	6.92(62)	1.45(1.6)	1.44(1.6)	1.87(3.0)	2.59(6.2)	83.6
Metribuzin (200 g/ha)	7.41(54)	5.02(25)	3.02(9)	8.86(93)	1.93(3.2)	1.61(2.1)	2.30(4.8)	3.42(11.2)	75.3
Weedy check	15.0(224)	10.6(111)	6.39(40)	19.9(377)	3.13(9.3)	2.98(8.4)	4.34(18.3)	6.11(36.9)	0.0
LSD (p=0.05)	0.05	0.04	0.06	0.04	0.16	0.03	0.03	0.04	-

Original figures in parentheses were subjected to square-root transformation $\sqrt{x+0.5}$ before statistical analysis

Table 2. Effect of crop establishment and weed management practices on weed and growth stage of wheat (pooled data of two years)

Treatment	Plant population at 15 DAS	Plant height at harvest (cm)	No. of tillers/m^2 at harvest	Plant dry weight at 60 DAS (g/m^2)	Leaf area index at 60 DAS	Root volume at 60 DAS (cc/plant)
Tillage practices						
Conventional tillage	181	93.9	323	34.6	2.62	13.2
Zero-tillage without residue	188	94.4	329	30.9	2.52	12.0
Zero-tillage with residue	164	97.1	407	38.6	3.03	14.0
Zero-tillage with residue burning	154	95.3	376	36.7	2.85	13.7
LSD (p=0.05)	NS	1.45	61.7	2.60	0.24	NS
Weed management practices						
Mesosulfuron + idosulfuron (12+2.4 g/ha)	177	93.3	372	33.5	2.47	12.0
Sulfosulfuron + metsulfuron (32 g/ha)	197	95.4	416	38.1	2.79	13.3
Metribuzin (200 g/ha)	155	95.2	377	36.1	2.71	13.3
Weedy check	181	96.9	269	33.1	3.06	14.2
LSD (p=0.05)	NS	2.07	43.2	1.71	0.27	NS

Table 3. Effect of crop establishment and weed management practices on yield attribute and yield of wheat (pooled data of two years)

Treatment	Spike length (cm)	No. of grains/ spike	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Net returns ($x10^3$ `/ha)	B:C ratio
Tillage practices								
Conventional tillage	10.61	53.5	39.3	3.23	4.30	42.97	31.96	1.15
Zero-tillage without residue	10.51	52.5	39.4	3.13	3.80	45.19	29.99	1.36
Zero-tillage with residue	11.07	60.8	42.6	3.86	4.80	44.38	36.18	1.86
Zero-tillage with residue burning	11.07	55.1	40.8	3.43	4.32	44.27	35.84	1.74
LSD (p=0.05)	0.30	2.80	2.35	0.21	0.55	-	-	-
Weed management practices								
Mesosulfuron + iodosulfuron (12+2.4 g/ha)	10.47	53.7	39.7	3.47	4.02	46.33	35.26	1.65
Sulfosulfuron + metsulfuron (32 g/ha)	11.10	56.8	41.9	3.90	4.93	44.12	36.79	1.88
Metribuzin (200 g/ha)	10.60	51.5	39.8	3.54	4.89	42.01	35.97	1.73
Weedy check	11.08	59.9	40.7	2.75	3.40	44.69	24.81	1.02
LSD (p=0.05)	0.51	1.90	1.70	0.26	0.53	-	-	-

parameters attained the superior value under ready mix herbicide of sulfosulfuron + metsulfuron and which was at par with mesosulfuron + iodosulfuron controlling weeds at higher level.

Yield attributes and yield

The grain yield of wheat crop was varied significantly due to different tillage and weed management practices (**Table 3**). The significantly higher spike length, grains/spike and test weight was recorded in zero-tillage with residue retention practice and which was at par with zero-tillage with residue burning. Among the different tillage practices, the maximum grain and straw yield were recorded under zero-tillage with residue retention practice, and the minimal one was observed in case of zero-tillage without residue. Increase in grain and straw yield may be attributed mainly to grains/spike, spike length and test weight which highly favored under zero-tillage with residue retention practice. However, the harvest index was not differed significant with various tillage practices. Similar results were reported by Mitra *et al*. (2014 and Kumar *et al*. (2016).

The yield attributing traits, *viz*. length of spike, grain/spike and test weight; grain and straw yields and harvest index were differed significantly due to various weed management practices. These attributes attained the poorest value under weedy check plot and improved due to application of sulfosulfuron + metsulfuron, mesosulfuron + iodosulfuron and metribuzin. The yield attribute character and yield of wheat was improved, remarkably, under the post-emergence application of sulfosulfuron + metsulfuron *fb* mesosulfuron + iodosulfuron and metribuzin.

Economics

Among the different tillage practices, the maximum net returns (` 36180 /ha) and benefit:cost (1.86) was found with zero-tillage with residue retention practice. Whereas, among various weed management practices application of sulfosulfuron + metsulfuron at 30 DAS gave the maximum net returns (` 36790 /ha) and benefit:cost ratio (1.88).

Thus, it can be inferred that zero-tillage with previous rice residue retention and application sulfosulfuron+metsulfuron at 30 DAS was the most productive and profitable in wheat.

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Tembotrione for post-emergence control of complex weed flora in maize

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ABSTRACT

Bio-efficacy of tembotrione 42% SC w/v (34.4% SC w/w), a new herbicide for post-emergence control of mixed weed flora in maize was evaluated during rainy seasons 2009 to 2015 at CCS Haryana Agricultural University, Regional Research Station, Karnal and also through multi-location adaptive/farmer-participatory trials. Post-emergence application of tembotrione 120 g/ha along with surfactant (1000 ml/ha) at 2-4 leaf stage was found most effective against grassy and non-grassy weeds as compared to other herbicidal treatments either applied as pre- or post-emergence (including its lower doses, atrazine and 2,4-D) resulting into the highest productivity (3.77-4.44 t/ha) and profitability (B-C ratio 1.75-1.98) of maize in on-station experiment during 2009-2010. On an average, grain yield of maize under tembotrione 120 g/ha along with surfactant (4.04-5.00 t/ha) was also better than the atrazine 500-750 g/ha (3.59-4.43 t/ha) and untreated check (2.86-3.33 t/ha) at multi-location trials during 2013-2015. There was no residual toxicity of tembotrione on succeeding wheat. Residues of tembotrione at 120 g/ha + S 1000 ml/ha and 240 g/ha + S 1000 ml/ha in raw cobs, grains and straw of maize and soil were also below detectable level during 2015.

INTRODUCTION

Maize (*Zea mays* L.) referred as "miracle crop" or the "queen" of cereals is one of the most important crop of the world and third most important crop of India after rice and wheat. It occupies an area of 9.23 mha with production of 25.66 mt and average productivity of 2.56 t/ha in the country (Anonymous 2015). In Haryana, maize area is only about 8,000-10,000 ha during last five years, but it has scopes as a potential crop in future to diversify the existing rice-wheat cropping system in the state. Maize holds potential for diversification and livelihood security as reported elsewhere (Das *et al*. 2012). But, weeds pose a major problem in rainy season maize due to congenial growth conditions primarily because of frequent rains, wide spacing and initial slow growth often inflicting huge losses ranging from 28 to 100% (Pandey *et al*. 2001, Das *et al*. 2012). Almost all types of weeds (grassy, broad-leaf weeds and sedges) infest the maize fields. Atrazine as pre-emergence is the most widely used herbicide in maize. It effectively controls broad-leaf weeds but control of sedges and some grasses remains a problem particularly in situation of variable soil moisture coupled with labour scarcity restricting the intercultural operations. Hence, there is a need for some post-emergence herbicide(s) for broad-spectrum weed control in maize. The post-emergence herbicide tembotrione 42% SC w/v (34.4% SC w/w), which belongs to triketone group, inhibits the enzyme hydroxyphenylpyruvate dioxygenase (HPPD) and is absorbed mainly by the leaves. It is co-formulated with the safener isoxadifen-ethyl as a liquid oil dispersion. It was evaluated against mixed weed flora in maize at multi-locations during 2009 to 2015 including its residues in maize and soil.

MATERIALS AND METHODS

Field experiment-1 (bio-efficacy evaluation)

A field experiment to evaluate the efficacy of tembotrione 42% SC w/v (34.4% SC w/w) for post-emergence control of mixed weed flora in maize was conducted during rainy seasons 2009 and 2010 at CCS Haryana Agricultural University, Regional Research Station, Karnal. The soil of the experimental field was clay loam in texture, low in available N, medium in P_2O_5 and high in K_2O with slightly alkaline in reaction (pH 8.1). The treatments included tembotrione 100, 110 and 120 g/ha each with 1000 ml/ha surfactant or without surfactant applied at 2-4 leaf stage (LS), atrazine 750 and 1000 g/ha applied as pre-emergence at 0-3 days after sowing (DAS), 2,4-D-Na 800 g/ha at 3 weeks after sowing (WAS), along with twice hand weeding and weedy check. The treatments were laid out in a randomized complete block design and replicated thrice. The herbicides were sprayed with knapsack sprayer fitted with flat-fan nozzle using water volume of 500 l/ha. Tembotrione was applied at 2-4 leaf stage of the weeds (10-15 DAS). During 2009, maize hybrid *'HM-1'* was sown on 27th June and during 2010 hybrid '*HQPM-1*' was sown on 27th June with a spacing of 75 x 20 cm using seed rate of 20 kg/ha. Sowing was done on north side of the east-west ridges by dibbling method followed by irrigation up to half ridge on the next day. Plot size was 5.0 x 4.5 m during 2009 and 5.0 x 3.0 m during 2010. Density and dry weight of weeds were recorded at 30 days after treatment (DAT) and 45 DAT, respectively. Phyto-toxicity in terms of chlorosis, stunting, leaf burning and epinasty was recorded at 7, 15, 30 and 45 DAT on 0-10 scale during 2009 and 2010. Crop was raised according to package of practices of the State Agricultural University and harvested on 26th September 2009 and 28th September 2010.

Field experiment-2 (residual phyto-toxicity evaluation)

For crop phyto-toxicity on maize and residual toxicity on wheat crop, an experiment was laid out at Regional Research Station (RRS), Karnal during rainy seasons 2011 and 2012. The treatments included tembotrione 42% SC w/v (34.4% SC w/w) 120 g/ha + S, tembotrione 240 g/ha + S and untreated check laid out in a randomized completely block design and replicated thrice. The plot size was 5.0 x 4.5 m. Maize hybrid '*HM-4*' was sown on 27th June 2011 and 29th June 2012 with a row spacing of 75 cm using a seed rate of 20 kg/ha. Plant × plant spacing was maintained at 20 cm. Herbicide was applied at 15 DAS. Crop was raised according to package of practices of the State University. Crop phyto-toxicity on maize was recorded at 15 and 30 DAT on 0-10 scale. After harvest of maize, the succeeding wheat (*Var. HD2967*) was sown on 12th and 10th November during 2011 and 2012 using a seed rate of 100 kg/ha with a row spacing of 20 cm without disturbing the original layout. Residual phyto-toxicity on wheat was recorded at 30 and 45 DAS on 0-10 scale.

Adaptive/farmer-participatory trials

Adaptive/farmer-participatory trials were also conducted in Ambala, Karnal, Kaithal, Kurukshetra and Panchkula districts of Haryana during 2013-2015. The treatments included tembotrione 42%SC w/v (34.4% SC w/w) 120 g/ha + S (1000 ml/ha) at 2-4 LS, atrazine 50%WP 500-750 g/ha at 0-3 DAS and untreated check with plot size of ½ acre each. These adaptive trials were at 8, 8 and 6 locations (which served as number of replications) during rainy seasons of 2013, 2014 and 2015.

RESULTS AND DISCUSSION

Effect on weeds

Weed flora of the field consisted of mainly *Dactyloctenium aegyptium, Brachiaria reptans, Digitaria sanguinalis, Leptochloa chinensis, Echinochloa colona* among grasses and *Euphorbia hirta* and *Amaranthus viridis* among broad-leaf weeds, and *Cyperus rotundus* was the only sedge.

Density of grassy **(Table 1)**, broad-leaf (BLW) and sedges **(Table 2)** and dry weight of weeds (**Table 3)** decreased with successive increase in dose of the tembotrione 42% SC w/v (34.4% SC w/w) from 100 to 120 g/ha with or without surfactant. Addition of surfactant to tembotrione was realized essential to attain its satisfactory efficacy; as the density and dry weight of weeds decreased significantly when it was applied with surfactant at all the doses. Addition of surfactant was also realized essential to achieve satisfactory weed control efficacy of tembotrione against mixed weed flora in maize earlier also (Singh *et al.* 2012). Tembotrione with surfactant provided effective control of all type of weeds including *Cyperus rotundus* with maximum efficacy at tembotrione 120 g/ha + surfactant 1000 ml/ha. Tembotrione 120 g/ha + S resulted in significantly lower density of *Dactyloctenium aegyptium*, *Brachiaria reptans*, *Digitaria sanguinalis*, total grassy weeds and *Cyperus rotundus* in comparison to 100 and 110 g/ha + S. Similarly tembotrione 110 g/ha + S was superior to tembotrione 100 g/ha + S in reducing the density of these weeds. However, the differences among the three doses of tembotrione when applied with surfactant were not always significant in respect of density of grassy weeds *Leptochloa chinensis* and *Echinochloa colona*, and BLW. Tembotrione 120 g/ha + S resulted in significantly lower dry weight of grassy weeds and sedges as compared to 100 g/ha + S during both the years and tembotrione 110 g/ha + S during 2010. However, the differences between 120 g/ha + S and 110 g/ha + S in respect of dry weight of grassy weeds and sedges were non-significant during 2009. Similarly tembotrione 110 g/ha + S was at par with 100 g/ha + S in respect of dry weight of grassy weeds and sedges except 110 g/ha + S being superior during 2010. All the doses of tembotrione applied with surfactant were similar to each other in respect of dry weight of BLW.

Atrazine also provided good control of grassy and broad-leaf weeds during 2009 but control of grassy weeds was less during 2010. It was not effective against sedges. Efficacy of atrazine

Table 1. Effect of tembotrione on density (no. /m²)* of grassy weeds in maize at 30 days after application

Treatment	Dose (g/ha)	Time of application	*Dactyloctenium aegyptium*		*Brachiaria reptans*		*Leptochloa chinensis*	*Echinochloa colona*	*Digitaria sanguinalis*	Total grassy weeds	
			2009	2010	2009	2010	2009	2009	2010	2009	2010
Tembotrione+S	100+1000	2-4 LS	3.31(10.0)	2.51(5.3)	3.00(8.0)	4.28(17.3)	1.24(0.7)	1.24(0.7)	3.68(12.7)	4.51(19)	6.02(35)
Tembotrione+S	110+1000	2-4 LS	3.00(8.0)	2.24(4.0)	2.76(6.7)	3.51(11.3)	1.24(0.7)	1.24(0.7)	3.08(8.7)	4.12(16)	5.00(24)
Tembotrione+S	120+1000	2-4 LS	1.90(2.7)	1.66(2.0)	1.73(2.0)	3.00(8.0)	1.24(0.7)	1.24(0.7)	2.20(4.0)	2.63(6)	3.87(14)
Tembotrione	100	2-4 LS	5.79(32.7)	3.21(9.3)	5.31(27.3)	5.25(26.7)	2.20(4.0)	1.90(2.7)	5.24(26.7)	8.21(67)	7.97(63)
Tembotrione	110	2-4 LS	5.11(25.3)	3.11(8.7)	4.93(23.3)	5.13(25.3)	2.07(3.3)	1.73(2.0)	4.71(21.3)	7.40(54)	7.50(55)
Tembotrione	120	2-4 LS	5.31(27.3)	2.51(5.3)	4.79(22.0)	4.71(21.3)	2.07(3.3)	1.73(2.0)	4.43(18.7)	7.45(55)	6.80(45)
2,4-D Na	800	3 WAS	6.85(46.0)	4.99(24.0)	6.50(41.3)	6.70(44.0)	2.65(6.0)	2.24(4.0)	4.92(23.3)	9.91(97)	9.60(91)
Atrazine	750	0-3 DAS	2.73(8.0)	3.40(10.7)	2.54(6.7)	5.13(25.3)	1.24(0.7)	1.00(0.0)	3.77(13.3)	3.60(15)	7.09(49)
Atrazine	1000	0-3 DAS	1.82(2.7)	3.21(9.3)	1.82(2.7)	4.58(20.0)	1.00(0.0)	1.00(0.0)	3.09(8.7)	2.33(5)	6.24(38)
Two hand weeding		20&40 DAS	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0)	1.00(0)
Weedy check			6.81(45.3)	3.78(13.3)	6.30(38.7)	6.60(42.7)	2.37(4.7)	2.07(3.3)	5.19(26.0)	9.64(92)	9.11(82)
LSD (p=0.05)			1.03	0.50	0.87	0.48	0.48	0.42	0.61	1.43	0.53

*Original figures in parentheses were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis; Abbreviations: S, surfactant, LS, leaf stage, WAS, weeks after sowing, DAS, days after sowing

Table 2. Effect of tembotrione on density (no. /m²)* of broad-leaf weeds and sedges in maize at 30 days after application

Treatment	Dose (g/ha)	Time of application	Broad-leaf weeds				Sedges (*Cyperus rotundus*)	
			Euphorbia hirta	*Amaranthus viridis*	Total BLW			
			2009	2009	2009	2010	2009	2010
Tembotrione+S	100+1000	2-4 LS	1.49(1.3)	1.24(0.7)	1.66(2.0)	1.66(2.0)	7.50(55.3)	5.26(26.7)
Tembotrione+S	110+1000	2-4 LS	1.49(1.3)	1.00(0.0)	1.49(1.3)	1.00(0.0)	5.44(28.7)	3.69(12.7)
Tembotrione+S	120+1000	2-4 LS	1.24(0.7)	1.00(0.0)	1.24(0.7)	1.00(0.0)	3.24(12.0)	2.58(6.0)
Tembotrione	100	2-4 LS	1.73(2.0)	1.24(0.7)	1.90(2.7)	2.51(5.3)	8.88(78.0)	7.72(58.7)
Tembotrione	110	2-4 LS	1.49(1.3)	1.00(0.0)	1.49(1.3)	1.24(0.7)	8.72(75.3)	6.13(36.7)
Tembotrione	120	2-4 LS	1.49(1.3)	1.00(0.0)	1.49(1.3)	1.00(0.0)	7.54(56.0)	5.62(30.7)
2,4-D Na	800	3 WAS	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.87(4.0)	4.57(20.0)
Atrazine	750	0-3 DAS	1.24(0.7)	1.00(0.0)	1.24(0.7)	1.00(0.0)	9.21(84.0)	5.80(32.7)
Atrazine	1000	0-3 DAS	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	9.36(86.7)	5.43(28.7)
Two hand weeding		20 and 40 DAS	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)
Weedy check			3.78(13.3)	1.90(2.7)	4.12(16.0)	3.11(8.7)	9.03(86.7)	6.45(40.7)
LSD (p=0.05)			0.53	0.36	0.60	0.43	1.33	0.64

*Original figures in parentheses were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis; Abbreviations: BLW, broad-leaf weeds, S, surfactant, LS, leaf stage, WAS, weeks after sowing, DAS, days after sowing

increased with increase in its dose from 750 to 1000 g/ha (**Tables 1-3**). Tembotrione 120 g/ha + S was at par with atrazine 1000 g/ha during 2009 but superior during 2010 in respect of density and dry weight of grassy weeds, whereas it was superior to atrazine 750 g/ha during both the years. Tembotrione 110-120 g/ha + S was similar to atrazine 750-1000 g/ha in respect of density of BLW; but superior in respect of density of sedges during both the years. Density and dry weight of grassy weeds under tembotrione 100-110 g/ha + S was lower than atrazine 750-1000 g/ha except being at par with atrazine 750 g/ha and higher than atrazine 1000 g/ha during 2009. 2, 4-D Na 800 g/ha provided good control of BLW and sedges but it was ineffective against grassy weeds. Tembotrione 100-120 g/ha was similar to atrazine and 2,4-D Na treatments in respect of density and dry weight of BLW. Dry weight of *Cyperus rotundus* under tembotrione 120 g/ha + S was similar to 2, 4-D Na during 2009 but lower during 2010 and was significantly lower than the atrazine treatments during both the years. Post-emergence application of tembotrione 120 g/ha along with surfactant was found most effective against grassy and non-grassy weeds as compared to other herbicides either applied as pre- or post-emergence (Singh *et al*. 2012) and even as good as weed free check (Singh *et al*. 2017).

Grain yield of maize

Tembotrione 120 g/ha + S 1000 ml/ha provided the maximum grain yield (3.77 t/ha during 2009 and 4.44 t/ha during 2010) and was superior to all other herbicidal treatments (**Table 3**). However, grain yield of maize under tembotrione 110 g/ha + S 1000 ml/ha (3.31 t/ha during 2009 and 4.00 t/ha during 2010) was at par with two hand weeding during 2009, but was inferior to hand weeding during 2010 and tembotrione 120 g/ha + S during both the years. Post-emergence application of tembotrione 120 g/ha along with surfactant has been reported most effective against complex weed flora resulting into the highest grain yield of maize earlier also (Singh *et al*. 2012). The benefit-cost ratio (1.75-1.98) was also highest under tembotrione 120 g/ha + S during both the years

Table 3. Effect of tembotrione on dry weight of weeds at 45 days after herbicide application, grain yield of maize and B-C ratio

Treatment	Dose (g/ha)	Time of application	Dry weight of weeds (g/m^2)						Grain yield (t/ha)		B: C ratio	
			Grassy weeds		BLW		Sedges					
			2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Tembotrione+S	100+1000	2-4 LS	43.4	52.4	0.9	1.2	26.7	6.4	3.11	3.56	1.55	1.69
Tembotrione+S	110+1000	2-4 LS	34.5	33.1	1.3	0.0	14.4	4.2	3.31	4.00	1.61	1.84
Tembotrione+S	120+1000	2-4 LS	13.7	16.1	0.6	0.0	8.3	1.5	3.77	4.44	1.75	1.98
Tembotrione	100	2-4 LS	88.3	93.1	5.1	2.5	40.3	15.6	2.62	2.78	1.38	1.42
Tembotrione	110	2-4 LS	84.8	86.7	3.2	0.5	27.9	9.7	2.64	3.06	1.38	1.52
Tembotrione	120	2-4 LS	69.7	76.4	2.1	0.0	25.6	5.4	2.75	3.39	1.41	1.62
2,4-D Na	800	3 WAS	165.6	187.8	0.0	0.0	2.9	9.3	2.27	1.65	1.35	1.08
Atrazine	750	0-3 DAS	54.8	115.4	0.6	0.0	59.0	18.3	3.15	2.59	1.66	1.42
Atrazine	1000	0-3 DAS	10.7	82.8	0.0	0.0	44.6	17.3	3.30	2.97	1.69	1.54
Two hand weeding		20&40 DAS	0.0	0.0	0.0	0.0	0.0	0.0	3.56	4.50	1.48	1.75
Weedy check			160.7	196.5	6.0	5.7	36.4	20.0	1.77	1.72	1.20	1.14
LSD (p=0.05)			20.9	15.3	2.3	1.0	15.2	2.6	0.44	0.40	-	-

Abbreviations: BLW, Broad-leaf weeds, S, Surfactant, LS, Leaf stage, WAS, Weeks after sowing, DAS, Days after sowing

Table 4. Performance of tembotrione against weeds in maize under adaptive/farmer-participatory trials (2013 to 2015)

Treatment	Dry weight of weeds (g/m^2)			Grain yield of maize (t/ha)		
	2013	2014	2015	2013	2014	2015
Tembotrione+S 120 g/ha	15	5	2	5.00	4.04	4.46
Atrazine 500-750 g/ha*	58	52	54	4.43	3.59	3.68
Untreated check	261	255	230	3.33	2.86	2.95
LSD (p=0.05)	55	40	60	0.36	0.25	0.24

*Atrazine 500 g/ha at 1, 3 and 1 locations in 2013, 2014 and 2015, respectively. Locations in 2013(8): 1(Gola), 1(Majri Jattan),3(Azimgarh, Bhagal and Rasina), 1(Danghali) and 1(Uchani) in Ambala, Punchkula, Kaithal, Kurukshetra and Karnal districts, respectively. Locations in 2014(8): Majri Jattan(3), Basolan(1), Khera(2) and Rathpur(2) in Punchkula district. Locations in 2015(6): Majri Jattan(3) and Baar(3) in Punchkula district.

(**Table 3**), and it was realized to be the best treatment.

Adaptive/farmer-participatory trials

The data from adaptive/farmer-participatory trials indicated that tembotrione 42% SC w/v (34.4% SC w/w) 120 g/ha + S (1000 ml/ha) provided very good control (94-99%) of all type of weeds and the reduction in dry weight of weeds was more than the check atrazine 50%WP (78-82%) across three seasons (2013-2015); however, the differences were significant in 2014 (**Table 4**). On an average, grain yield of maize under tembotrione (4.04-5.00 t/ha) was better than the atrazine treatment (3.59-4.43 t/ha) and untreated check (2.86-3.33 t/ha).

Phyto-toxicity on maize and residual toxicity on wheat

There was no phyo-toxicity of tembotrione 100-120 g/ha (with or without surfactant) on maize in terms of chlorosis, stunting, leaf burning and epinasty at 7, 15, 30 and 45 DAT in field experiment-1 during 2009 and 2010 (data not given). Also, there was no phyto-toxicity of tembotrione at 120 and 240 g/ha (with surfactant) on maize at 15 and 30 DAT and no residual phyto-toxicity on succeeding crop of wheat during 2011 and 2012 in field experiment-2 (data not given). Singh *et al.* (2012) also reported that there was no phyto-toxicity of tembotrione on maize and succeeding crop of mustard in rotation.

Based on present investigation, it can be concluded that tembotrione 120 g/ha + S 1000 ml/ha applied at 2-4 leaf stage provided satisfactory control of all type of weeds (grassy weeds, broad-leaf weeds and sedges) in rainy season maize without causing any crop phyto-toxicity on maize and consequently, it resulted into higher grain yield and profitability. Addition of surfactant was realized a must to attain satisfactory efficacy of tembotrione against mixed weed flora in maize. There was no phyto-toxicity of tembotrione 120 and 240 g/ha on maize and also no residual toxicity on succeeding crop of wheat. Residues of tembotrione at 120 g/ha + S 1000 ml/ha and 240 g/ha + S 1000 ml/ha in raw cobs, grains and straw of maize and soil were also below detectable level.

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Herbicide options for effective weed management in zero-till maize

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ABSTRACT

A field experiment was carried out during winter seasons of 2015-16 and 2016-17 at Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal with the objective of identifying weed management options with various pre- and post-emergence herbicides in zero-till maize in rice-maize cropping system. Three pre-emergence herbicides, *viz*. pendimethalin 1.0 kg/ha, atrazine 1.0 kg/ha and control in main plots and six post-emergence treatments, *viz*. atrazine (0.5 kg/ha), tembotrione (120 g/ha), halosulfuron (90 g/ha), tembotrione (120 g/ha) + atrazine (0.5 kg/ha), halosulfuron(90 g/ha) + atrazine (0.5 kg/ha) and control in sub-plots were evaluated in a split-plot design. Results revealed that both pendimethalin and atrazine reduced the grassy weed population to a significant extent and among the pre-emergence herbicides, atrazine resulted in maximum reduction in grass weed population (69% reduction over the weedy check) at 20 days after seeding (DAS). Among the post-emergence herbicides, mixture of tembotrione + atrazine was more effective in controlling all classes of weed flora at 40 and 60 DAS. Tembotrione alone also showed a good control of grasses and broad-leaved weeds. Atrazine as pre-emergence followed by (*fb*) tembotrione + atrazine as post-emergence had significantly lower weed biomass (2.9 and 7.5 g/m^2 at 40 and 60 DAS, respectively) and this combination reduced the weed dry matter to the tune of 98.7 and 97.9% at 40 and 60 DAS, respectively which ultimately resulted in significantly higher grain yields (11.57 t/ha) with maximum net returns (` 74210/ha) and B: C ratio (2.73). A strong negative correlation between weed biomass at 60 DAS and maize grain yield clearly suggested that weed biomass accounted for 55% variation in grain yield of zero-till maize.

INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal crop after rice and wheat, which is widely grown in the world and is used as primary staple food in many developing countries. Due to the wider adaptability and high yield potential of the crop, it can be included in many cropping systems.The increasing demand for maize is rapidly transforming cropping systems in certain parts of Asia (Yakadri *et al.* 2015). Significant shifts from rice monoculture to more profitable rice- maize systems have either occurred or are emerging (IRRI and CIMMYT 2006). This northern part of West Bengal has very high yield potential of winter maize and the areas under this cropping system are escalating day by day because of its increasing demand for fish feed, poultry feed, animal feed and starch industries in the eastern part of the country.

Under conventional rice-maize system, maize is grown by manual dibbling after intensive 5-6 tillage operations which delayed the maize sowing at least 2-3 weeks. Again, number of repetitive tillage operations increases the cost of cultivation as well as fuel consumption. Dibbling requires large number of labour which further increases the cost of cultivation. The conservation agriculture (CA) based new agronomic management practices offers to tackle these challenges. CA holds tremendous potential for all size of farm and agro-ecological system, but its adaptation is probably most urgently required by small land holder (FAO 2006).The direct seeded maize in no-till/strip till/permanent beds is an alternate option through mechanized precision planting in a single pass. Zero tillage technology has turned into a great success story and seems to be one of the best technologies after green revolution (Singh *et al.*

2010). After seeding through zero till-drill, one of the major challenges is the weed management, particularly due to lack of pre- and post-emergence herbicides in the region. Changes in patterns of tillage, planting systems, and other management strategies can alter the soil environment and lead to a major change in weed flora. Herbicide use has been an extremely important component of weed management in CA systems (Bhullar *et al.* 2016). The traditional weed management comprises of hand weeding and spading simultaneously for earthing-up to make furrow and ridges at 4-5 weeks after seeding, which is labour intensive but facilitates furrow irrigation. However, weed control in the early part of the growing season is very important due to its initial slow growth rate and wider row spacing. Yield losses due to weed infestation may vary from 28-93% depending on the type of weed flora and their intensity, stage, nature and duration of crop weed competition (Sharma and Thakur 1998). Uncontrolled weeds in maize caused yield reduction in the range of 40 to 60% depending upon the intensity and types of weed flora (Sunitha and Kalyani 2012).

To address the weed management problems in zero-till maize, different weed management options with various pre- and post-emergence herbicides were evaluated.

MATERIALS AND METHODS

The experiment was carried out at Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar (26°24’02.2"N latitude, 89°23’21.7"E longitude and at an elevation of 43 meters above mean sea level) during winter seasons of 2015-16 and 2016-17. The soil was sandy loam in texture with good drainage facility with 0.90% organic C, 127.50 kg/ha of mineralizable N, 17.3 kg/ha of available phosphorus, 122.9 kg/ha of available potassium with a pH of 5.54. The experiment was laid out in a split-plot design. Three pre-emergence herbicides, *viz*. pendimethalin at 1.0 kg/ha, atrazine at 1.0 kg/ha, and no application were taken in main plots while six post-emergence treatments, *viz*. atrazine (0.5 kg/ha), tembotrione (120 g/ha), halosulfuron (90 g/ha), tembotrione (120 g/ha) + atrazine (0.5 kg/ha), halosulfuron (90 g/ha) + atrazine (0.5 kg/ha), and no application were taken in sub-plots, each replicated thrice. Glyphosate 41% S.L. at 3.75 litre/ha was applied 7 days prior to sowing for killing the existing weed flora. Seeds of hybrid maize ‘*DKC 9081*’ of 150-155 days duration were placed in lines 60 cm apart through a 9 tyne National Agromake zero-till seed-cum-fertilizer drill and a seed to seed distance of 20 cm was maintained. The fertilizer dose was kept at 170 kg nitrogen, 80 kg phosphorus and 100 kg potassium/ha. Nitrogen was applied in three splits (30 kg/ha as basal through 10-26-26 complex fertilizer at the time of seeding with drill, 70 kg/ha at 4 weeks after sowing and rest 70 kg/ha at 7 weeks after sowing). Full dose of phosphorus (80 kg/ha) along with 80% potassium (80 kg/ha) were applied with 10-26-26 complex fertilizer at the time of seeding with drill, while the rest 20% potassium (20 kg/ha) was applied during second top-dressing.

Herbicides were applied with knapsack sprayer fitted with a flat-fan nozzle and water as a carrier at 500 litre/ha for pre-emergence spray and at 375 litre/ha for post-emergence spray. A three nozzles boom with flat-fan nozzle tip was used for spraying. Tank mix 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 weed count was taken from four permanent quadrates before application of post-emergence herbicides. For weed count and weed biomass at 20 days after post-emergence herbicide application, count was taken from all four permanent quadrates and weed biomass from only two random quadrates. Weed count and biomass at 40 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. Grain yield was measured from the entire plot area of 15 m^2 and expressed in kg/ha at 14% moisture.

Data on weed density was 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 p=0.05) test. Entire statistical analysis was carried out using Statistical Analysis System (SAS) software (version 9.2). Economics of the treatments was computed based on the existing market price.

RESULTS AND DISCUSSION

Weed flora

The weed flora emerged during the period of experimentations included grasses like *Cynodon dactylon* and *Digitaria ciliaris*; sedges like *Cyperus iria* and *Cyperus rotundus*; broad-leaved like

Polygonum pensylvanicum, Polygonum persicaria, Polygonum orientale, Stellaria media, Chenopodium album, Ageratum conyzoides, Solanum nigrum, Physalis minima, etc. During the initial period, grass weeds dominated the weed flora along with some sedge, whereas broad-leaved weeds especially *Polygonum* spp. emerged at 20 days after seeding and remained continuous throughout the growth stages. Earlier, Mukherjee and Rai (2016) reported the severe infestation of *Polygonum* spp. in dibbled maize under zero till condition.

Weed density

Grass weeds density at 20 days after seeding (DAS), following pre-emergence application of pendimethalin and atrazine, was reduced as compared to no pre-emergence application (**Table 1**). Both pendimethalin and atrazine reduced the grassy weed population to a significant extent and among the herbicides, atrazine resulted in maximum reduction in grass weed population (69% reduction over the weedy check) at 20 DAS. Deshmukh *et al.* (2009) reported similar results of lowest weed population with pre-emergence atrazine in maize. Chopra and Angiras (2008) also reported that atrazine as pre-emergence was found promising in reducing weed biomass. Assessment of weed density at 40 and 60 DAS also showed good efficacy of these herbicides.Though there was not much sedge in the experimental field, but the density of sedges following the application of pre-emergence herbicides was also lower than the weedy check in all dates. Application of pre-emergence atrazine had also a great impact in controlling the broad-leaved weeds as reflected from the weed density data at 20 DAS. Among the post-emergence herbicides, tembotrione + atrazine was more effective in controlling all sorts of weed flora at 40 and 60 DAS. Tembotrione alone also showed a good control of grasses and broad-leaved weeds. In our study, the pre-emergence application of atrazine helped to prevent the germination and establishment of the initial flush of grass weeds and small-seeded broad-leaf weeds as the atrazine treated plots were largely free from these weeds for initial 20 DAS. However, atrazine alone could not prevent the establishment of weeds at later stages for which post-emergence herbicides had to be applied. Under the circumstances, tembotrione alone or tembotrione+ atrazine had a greater control on wide-spectrum of weed flora. Among the other post-emergence herbicides, atrazine alone was also quite effective in controlling the broad-leaved weeds.

Weed biomass and WCE

Weed biomass at 40 and 60 DAS varied significantly among various herbicide combinations. The control plots had the highest weed dry matter (226.8 and 353.4 g/m^2 at 40 and 60 DAS, respectively). Atrazine as pre-emergence *fb* tembotrione + atrazine as post-emergence had significantly lower weed dry matter production (2.9 and 7.5 g/m^2 at 40 and 60 DAS, respectively). This combination reduced the weed dry matter to the tune of 98.7 and 97.9% as revealed from maximum WCE (**Table 2**). Mukherjee and Rai (2016) reported higher WCE with pre-emergence atrazine followed by post-emergence atrazine in dibbled maize under zero-till condition. At 40 and 60 DAS, application of tembotrione alone as post-emergence with pre-emergence atrazine or pendimethalin also recorded lower weed dry weight which was at par with the application of atrazine as pre-emergence *fb* tembotrione + atrazine as post-emergence. Tembotrione alone or in combination with atrazine as

Table 1. Weed density at different stages under various herbicides combinations (pooled over 2 years)

Treatment	Grasses (no./m^2)			Sedges (no./m^2)			Broad-leaves (no./m^2)		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Pre-emergence herbicides									
No Pre-emergence	10.85(116.7)	6.74(44.4)	7.40(53.8)	3.19(9.18)	1.38(0.90)	1.41(0.99)	5.49(29.1)	2.61(5.81)	3.05(8.30)
Pendimethalin 1000 g/ha	6.65(43.2)	5.50(29.2)	6.71(44.0)	3.06(8.36)	1.00(0)	1.09(0.19)	4.24(17.0)	2.42(4.86)	2.50(5.25)
Atrazine 1000 g/ha	6.09(36.1)	5.24(26.5)	6.03(35.4)	1.99(2.96)	1.00(0)	1.00(0)	2.62(5.9)	2.10(3.41)	1.93(2.72)
LSD (p=0.05)	0.18	0.14	0.16	0.15	0.04	0.03	0.16	0.07	0.08
Post-emergence herbicides									
No application	7.78(59.5)	9.08(81.4)	10.26(104.3)	2.83(7.01)	1.76(2.10)	1.83(2.35)	4.12(16.0)	5.06(24.60)	5.16(25.63)
Atrazine 500 g/ha	7.79(59.7)	5.05(24.5)	5.85(33.2)	2.60(5.76)	1.00(0)	1.00(0)	4.07(15.6)	1.00(0)	1.66(1.76)
Tembotrione 120 g/ha	7.94(62.0)	3.64(12.2)	4.82(22.2)	2.72(6.40)	1.00(0)	1.00(0)	4.08(15.6)	1.00(0)	1.00(0)
Halosulfuron 90 g/ha	7.94(62.0)	8.24(66.9)	8.39(69.4)	2.70(6.29)	1.00(0)	1.00(0)	4.17(16.4)	4.22(16.81)	4.56(19.79)
Tembotrione + atrazine 120 + 500 g/ha	7.82(60.1)	2.42(4.9)	3.49(11.2)	2.62(5.86)	1.00(0)	1.00(0)	4.18(16.5)	1.00(0)	1.00(0)
Halosulfuron + atrazine 90 + 500 g/ha	7.82(60.1)	6.53(41.6)	7.51(55.4)	2.60(5.76)	1.00(0)	1.00(0)	4.09(15.7)	2.01(3.04)	1.57(1.46)
LSD (p=0.05)	NS	0.21	0.23	NS	0.05	0.05	NS	0.09	0.12

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

Table 2. Weed biomass and weed control efficiency under various herbicides combination (pooled over 2 years)

Pre-emergence herbicides	Post- emergence herbicides	Weed biomass (g/m^2)		WCE (%)	
		40 DAS	60 DAS	40 DAS	60 DAS
No application	No application	226.8	353.4	-	-
	Atrazine	16.5	57.0	92.7	83.9
	Tembotrione	9.9	36.8	95.7	89.6
	Halosulfuron	98.8	240.0	56.4	32.1
	Tembotrione + atrazine	8.5	12.3	96.3	96.5
	Halosulfuron + atrazine	36.5	68.6	83.9	80.6
Pendimethalin	No application	136.4	194.3	39.9	45.0
	Atrazine	20.0	47.9	91.2	86.5
	Tembotrione	9.8	26.3	95.7	92.5
	Halosulfuron	100.7	178.8	55.6	49.4
	Tembotrione + atrazine	3.3	14.6	98.6	95.9
	Halosulfuron + atrazine	46.8	67.9	79.4	80.8
Atrazine	No application	111.6	152.2	50.8	56.9
	Atrazine	19.1	68.4	91.6	80.7
	Tembotrione	6.4	13.7	97.2	96.1
	Halosulfuron	84.5	83.5	62.7	76.4
	Tembotrione + atrazine	2.9	7.5	98.7	97.9
	Halosulfuron + atrazine	50.5	59.3	77.8	83.2
LSD(p=0.05)	Pre-emergence	2.8	3.8	-	-
	Post-emergence	4.1	5.5	-	-
	Pre X post-emergence	9.3	12.4	-	-

DAS= Days after seeding; For dose please see Table 1

a post-emergence without any pre-emergence herbicides application also had a significant impact in reducing the weed dry matter. Except halosulfuron, all the post-emergence herbicides recorded superior WCE values. It can be said that tembotrione alone or in combination with atrazine as post-emergence only even without any pre-emergence herbicides would be a potential option for broad-spectrum weed control in zero-till maize.

Yield and economics

The treatment receiving atrazine as pre-emergence and tembotrione + atrazine as post-emergence recorded significantly higher grain yields (11.57 t/ha). It was followed by tembotrione + atrazine as post-emergence with pre-emergence pendimethalin (10.65 t/ha) and tembotrione alone as post-emergence in combination with pre-emergence atrazine (10.63 t/ha), being at par with each other (**Table 3**). Triveni *et al.* (2017) reported the maximum grain yields in maize under this combination of herbicides. The treatments in which only pre-emergence herbicides were applied recorded lower grain yields than the treatments with only post-emergence application and the lowest grain yield was recorded with weedy check (4.14 t/ha). All sequential herbicide treatments resulted in better yield as compared to single application of a pre-emergence or post-emergence herbicides. It was observed that maize faced severe weed competition particularly from broad-leaved weeds if there was no application of post-emergence herbicides. However, after the spray of post-emergence herbicides, crop grew vigorously and did not allow the later flushes of weeds to grow which in turn resulted in better yield

Table 3. Grain yield and economics under various herbicides combination

Pre-Emergence herbicides	Post-emergence herbicides	Grain yield (t/ha)	Cost of cultivation (x103 `/ha)	Net returns (x10^3 `/ha)	B : C Ratio
No Pre-emergence	No application	4.14	38.47	4.99	1.13
	Atrazine	6.07	39.12	20.61	1.63
	Tembotrione	7.43	43.17	32.24	1.81
	Halosulfuron	4.75	45.82	6.05	1.09
	Tembotrione + atrazine	7.75	43.82	34.95	1.86
	Halosulfuron + atrazine	5.40	46.47	16.92	1.22
Pendimethalin	No application	4.89	39.77	10.97	1.29
	Atrazine	7.91	40.42	38.63	2.06
	Tembotrione	9.06	44.47	48.06	2.14
	Halosulfuron	5.14	47.12	9.20	1.15
	Tembotrione + atrazine	10.65	44.82	64.05	2.50
	Halosulfuron + atrazine	6.13	47.77	25.14	1.35
Atrazine	No application	5.47	39.27	17.56	1.47
	Atrazine	9.59	39.92	56.77	2.53
	Tembotrione	10.63	43.97	64.99	2.54
	Halosulfuron	5.90	46.62	17.38	1.33
	Tembotrione + atrazine	11.57	44.62	74.21	2.73
	Halosulfuron + atrazine	6.48	47.27	68.04	1.44
LSD(p=0.05)	Pre-emergence	0.19	-	-	-
	Post-emergence	0.27	-	-	-
	Pre X post-emergence	0.45	-	-	-

For dose please see Table 1

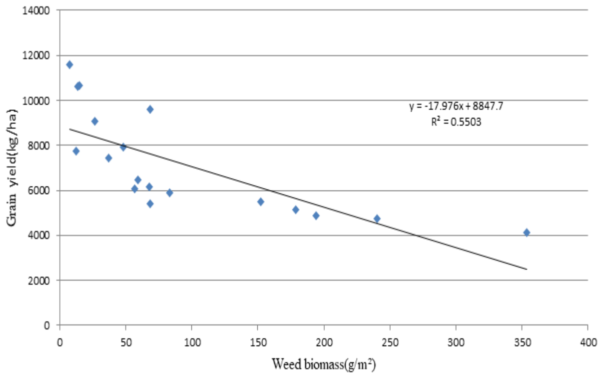

Figure 1. Relationship between weed biomass (g/m^2) and grain yield (kg/ha)

performances. A strong negative correlation between weed biomass at 60 DAS and maize grain yield clearly suggested that weed biomass accounted for 55% variation in grain yield (**Figure 1**).

The net returns and B: C ratio increased sharply when herbicides were used in combination with both pre-emergence and post-emergence. When atrazine as pre-emergence was combined with tembotrione + atrazine as post-emergence, the net returns (` 74210/ ha) and B: C ratio (2.73) were recorded maximum. This was in conformity with the findings of Triveni *et al.* (2017) who reported higher returns with the use of this herbicides combination in conventionally planted maize. Even tembotrione alone as post-emergence with either pre-emergence atrazine or pendimethalin resulted in increased yield performances. Tembotrione+atrazine as post-emergence with pre-emergence pendimethalin also recorded a superior returns and benefits signifying the impact of this herbicide combination irrespective of the pre-emergence herbicides used in this experiment. Barla *et al.* (2016) reported that pre-emergence atrazine or pendimethalin were equally effective in achieving higher productivity, profitability through better weed control in maize. Based on relative net profit, tembotrione alone as post-emergence could also be advocated with pre-emergence atrazine. On the basis of field study, it can be concluded that atrazine as pre-emergence combined with tembotrione + atrazine as post-emergence would be the most effective herbicides combination for controlling various weed flora in maize under zero till condition.

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Efficacy and economics of imidazolinone herbicides in cluster bean and their residual effect on mustard

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ABSTRACT

A field experiment was carried out at two different locations, research area of CCS HAU Hisar and farmer's field (Kheri Batter) to study efficacy and economics of imidazolinone herbicides in cluster bean during *Kharif* 2013 and their carryover effect on mustard was observed during *Rabi* 2014. Significantly higher herbicide efficiency index (HEI) was observed under PE application of pendimethalin + imazethapyr 1000 g/ha and tank mixture 500 g + imazethapyr 50 g/ha at 30 DAS and these two treatments also provided better control of weeds at 60 DAS without any phytotoxic effect on cluster bean at both the locations. At 30 DAS, less dry weight of weeds was recorded under pendimethalin 1000 g/ha as PE, but at 60 DAS, due to new emergence of weeds, percent weed control reduced due to more dry weight of weeds, thus HEI was lower under pendimethalin 1000 g/ha PE. At 60 DAS, PoE application of imazethapyr 100 g/ha *fb* propaquizafop 62.5 g/ha provided the highest HEI which was at par with pendimethalin + imazethapyr (ready and tank mixture), but at Hisar, HEI of imazethapyr + imazamox at all the doses was lower due to heavy infestation of *T. portulacastrum* as compared to other herbicidal treatments. The lowest weed index (WI) was observed under pendimethalin 500 g + imazethapyr 50 g/ha (tank mixture) as PE which was significantly at par with pendimethalin + imazethapyr (RM) 1000 g/ha as PE and imazethapyr 75 and 100 g/ha *fb* propaquizafop 62.5 g/ha, but significantly higher WI was recorded under imazethapyr + imazamox due to lower efficacy against *T. portulacastrum*. The highest biological yield, seed yield, maximum net returns and increase over weedy check were obtained under pendimethalin 500 g + imazethapyr 50 g/ha (tank mixture) as PE and pendimethalin + imazethapyr (RM) 1000 g/ha as PE, but both were statistically similar to each other and similar to PoE imazethapyr 100 g/ha *fb* propaquizafop 62.5 g/ha at both the locations. No injury was visible at 2 WAS, 4 WAS and later stages on mustard.

INTRODUCTION

The imidazolinone herbicides are known to be very effective in controlling annual and perennial broad-leaved and grass weeds in crops. These herbicides inhibit acetolactate synthase (ALS) which is essential for nucleic acid synthesis, *viz*. leucine, valine and isoleucine (Stidham and Singh 1991). The potential of imidazolinones in legume crop production increases globally for farmers due to this flexibility in time and mode of application. Numerous PE and PoE herbicide tank and ready mixtures are available for legume production. Cluster bean (*Cyamopsis tetragonoloba* L.) commonly known as *guar* is considered as a drought tolerant, deep taproot legume and rotational crop grown during *Kharif* season in arid and semiarid regions. Growing *guar* can be used as a forage or green manure, as an industrial crop grown mainly for *guar* gum and meal remaining after gum extraction can be used as protein supplement for animals. According to Joshi and Arora (1993), cluster bean has gained much importance in recent past due to its multifarious industrial uses. The 80% of World of cluster bean production is contributed by India as a largest cluster bean producer and it is mainly cultivated under rainfed or restricted irrigation condition. Haryana is the 2nd largest producer of cluster bean after Rajasthan. Being a rainy season crop, a large number of weeds come up and compete with cluster bean for the limited water, nutrients and space, thereby reducing the crop yield considerably (Daulay and Singh 1982). Critical period of crop weed competition in cluster bean has been identified as 20-40 DAS and presence of weeds beyond this result in competition between weeds and crop caused 53.7% reduction in seed yield (Saxena *et al*. 2004). Severity of yield loss depends on the weed infestation and its duration. So cluster bean is poor competitor with weeds and weed management is essential to maximize yield. Persistence of herbicide in the soil is mainly governed by soil temperature and soil moisture. However, the carry over effect of these herbicides in cropping system is not much known, so there is a need to test the persistence of herbicides in the field.

MATERIALS AND METHODS

Field experiments were conducted at CCSHAU, Hisar, which is characterized by the semi-arid climate with hot and dry summers and extremely cold winters and farmer's field at Khari Batter, Bhiwani during the *Kharif* and *Rabi* seasons of 2013-14. Mean weekly maximum temperature fluctuated between 36.5 and 16.4^{O}C and minimum between 3.2 and 27.1^{O}C from June 2013 to April 2014. The major part of the annual rainfall is received during monsoon season *i.e*. June to mid-September. The crop received 594.3 and 500.5 mm of rainfall in the growing season at Hisar and Kheri Batter, respectively. Texture of soil at Hisar was sandy loam with pH 7.8 and organic carbon 0.3% and at Kheri Batter was loamy sand with pH 8.2 and organic carbon 0.24%. Soils were deficient in available N (112 and 103.7 kg/ha), medium in P (14.4 and 12 kg/ha) and sufficient in K (427 and 240 kg/ha) at Hisar and Kheri Batter, respectively. The experiments were laid out in a randomized block design (RBD) with 16 treatments and 3 replications. Treatment comprised of imidazolinone herbicides and their mixture *viz*. pendimethalin (1000 g/ha, PE), pendimethalin 500 g + imazethapyr 50 g/ha (tank mixture) PE, pendimethalin + imazethapyr (ready mixture) 1000 g /ha PE, imazethapyr + imazamox PoE at 43.75, 52.5, 61.5 and 70 g/ha at 3 WAS (weeks after sowing) alone and followed by (*fb*) propaquizafop 62.5 g/ha (6 WAS), imazethapyr (50, 75 and 100 g/ha *fb* propaquizafop 62.5 g/ha applied at 3 *fb* 6 WAS, weedy check and weed free. HG-563 variety of Cluster bean and RH-749 mustard variety was taken. At both the locations, crop was sown with the recommended seed rate (20 kg/ha) and spacing (30 × 15 cm) and fertilizer rate (20: 40: 20, N: P_2O_5: K_2O kg/ha) using seed-cum-fertilizer drill. All experimental data were analyzed using software S.P.S.S version 7.5.

Weed index and herbicide efficiency index was

$$\text{WI (\%)} = \frac{\text{Yield from weed free plot - Yield from particular treatment}}{\text{Yield from weed free plot}} \times 100$$

$$\text{HEI (\%)} = \frac{\text{Yield from treatment - Yield from control}}{\text{Yield from control}} \times 100 / \frac{\text{Dry matter of weeds in a treatment}}{\text{Dry matter of weeds in control}} \times 100$$

calculated with the help of equations:

RESULTS AND DISCUSSION

Weed index

At Hisar, the highest WI was observed under weedy plot (0.39%) due to more weed competition which was at par with alone application of imazethapyr + imazamox 43.75 g/ha at 3 WAS. Among herbicidal treatments, lowest WI was observed under pendimethalin 500 g + imazethapyr 50 g/ha as PE (0.0%) which was significantly similar to pendimethalin + imazethapyr (RM) 1000 g/ha as PE (0.01%) and imazethapyr 75 and 100 g/ha *fb* propaquizafop 62.5 g/ha (0.07 and 0.04, respectively), but significantly higher WI was recorded under imazethapyr + imazamox due to heavy infestation of *T. portulacastrum*and herbicide was less effective to that weed (**Table 1**). But at farmer's field (Kheri Batter), there was less infestation of *T. portulacastrum,* thus pendimethalin + imazethapyr (TM and RM), imazethapyr 100 g/ha *fb* propaquizafop 62.5 g/ha and imazethapyr + imazamox 70 g/ha at 3 WAS *fb* propaquizafop 62.5 g/ ha at 6 WAS were significantly at par with each other (**Table 1**).

Herbicide efficiency index

At 30 DAS, maximum HEI was observed under pendmethalin 500 g + imazethapyr 50 g/ha PE (14.8%) which was statistically similar to the pendimethalin + imazethapyr 1000 g/ha PE (10.4%) and both the treatments were statistically higher as compared to other herbicidal treatments because pre-emergence application of herbicides provided effective control of weeds. At 60 DAS, maximum HEI was recorded under imazethapyr 100 g/ha 3 WAS *fb* propaquizafop 62.5 g/ha (7%) which was at par with pemdimethalin + imazethapyr 1000 g/ha PE (6%) and pendimethalin 500 g + imazethapyr 50 g/ha (tank mixture) PE (5.7%) because these two pre-emergence herbicidal treatments provided season long control of multiple weed flora in clusterbean (**Table 1**). HEI of imazethapyr + imazamox was lower due to lower efficacy of imazethapyr + imazamox against *T. portulacastrum* in sandy loam soils.

Table 1. Herbicide efficiency index under different weed control treatments applied in cluster bean

Treatment	Weed Index (%)		Herbicide efficiency Index (%) at 30 DAS		Herbicide efficiency Index (%) at 60 DAS	
	Hisar	Farmer field	Hisar	Farmer field	Hisar	Farmer field
Pendimethalin (1000 g/ha) PE	0.29	0.19	2.3	2.2	1.2	1.7
Imazethapyr + imazamox (43.75 g/ha) 3 WAS	0.30	0.33	0.3	1.0	0.4	1.5
Imazethapyr + imazamox (52.5 g/ha) 3 WAS	0.25	0.26	0.7	1.5	1	1.8
Imazethapyr + imazamox (61.5 g/ha) 3 WAS	0.23	0.27	0.7	1.6	1	3.2
Imazethapyr + imazamox (70 g/ha) 3 WAS	0.16	0.17	2.2	2.5	2.4	4.6
Imazethapyr + imazamox *fb* propaquizafop (43.75 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	0.25	0.27	0.6	1.2	1.2	2.9
Imazethapyr + imazamox *fb* propaquizafop (52.5 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	0.22	0.22	0.9	1.5	2	3.9
Imazethapyr + imazamox *fb* propaquizafop (61.5 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	0.17	0.16	1.4	2.1	3.5	5.0
Imazethapyr + imazamox *fb* propaquizafop (70 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	0.12	0.10	2.4	2.8	5.3	6.4
Imazethapyr *fb* propaquazafop (50 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	0.22	0.16	1.3	1.7	3.1	4.5
Imazethapyr *fb* propaquazafop (75 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	0.15	0.07	2.6	2.3	5.5	6.5
Imazethapyr *fb* propaquazafop (100 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	0.00	0.04	3.4	4.9	7	9.5
Pendimethalin + imazethapyr (500 + 50 g/ha) PE	0.00	0.00	13.7	14.4	6	8.3
Pendimethalin + imazethapyr (1000 g/ha) PE	0.09	0.01	11.7	10.7	5.7	7.3
Weed free	0.00	0.00	-	-	-	-
Weedy check	0.55	0.39	-	-	-	-

Table 2. Comparative economics of different weed control treatments applied in cluster bean

Treatment	Hisar					Farmer field				
	Seed yield (t/ha)	Gross returns (x10^3 `)	Total cost of cultivation (x10^3 `)	Net returns (x10^3 `)	Increase over weedy check (x10^3 `)	Seed yield (t/ha)	Gross returns (x10^3 `)	Total cost of cultivation (x10^3 `)	Net returns (x10^3 `)	Increase over weedy check (x10^3 `)
Pendimethalin (1000 g/ha) PE	1.24	81.60	32.38	49.22	22.40	1.11	76.60	32.38	44.22	26.66
Imazethapyr + imazamox (43.75 g/ha) 3 WAS	1.02	61.84	32.10	29.74	2.94	1.10	76.12	32.10	44.02	26.47
Imazethapyr + imazamox (52.5 g/ha) 3 WAS	1.13	67.92	32.28	35.64	8.83	1.19	79.97	32.28	47.69	30.13
Imazethapyr + imazamox (61.5 g/ha) 3 WAS	1.11	74.24	32.45	41.79	14.98	1.21	84.74	32.45	52.30	34.74
Imazethapyr + imazamox (70 g/ha) 3 WAS	1.27	81.92	32.63	49.29	22.48	1.32	90.66	32.63	58.03	40.47
Imazethapyr + imazamox *fb* propaquizafop (43.75 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	1.11	69.84	33.10	36.74	9.93	1.19	81.13	33.10	48.02	30.47
Imazethapyr + imazamox *fb* propaquizafop (52.5 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	1.20	68.88	33.29	35.59	8.78	1.24	84.06	33.29	50.77	33.21
Imazethapyr + imazamox *fb* propaquizafop (61.5 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	1.29	81.92	33.46	48.46	21.66	1.31	89.78	33.46	56.33	38.78
Imazethapyr + imazamox *fb* propaquizafop (70 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	1.38	87.36	33.64	53.72	26.91	1.38	93.84	33.64	60.20	42.65
Imazethapyr *fb* propaquazafop (50 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	1.29	83.20	32.99	50.21	23.40	1.22	86.49	32.99	53.50	35.95
Imazethapyr *fb* propaquazafop (75 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	1.42	89.28	33.33	55.95	29.14	1.34	91.33	33.33	58.00	40.45
Imazethapyr *fb* propaquazafop (100 *fb* 62.5 g/ha) 3 WAS *fb* 6 WAS	1.47	91.52	33.84	57.68	30.87	1.57	103.63	33.84	69.79	52.24
Pendimethalin + imazethapyr (500 + 50 g/ha) PE	1.53	95.28	32.61	62.67	35.86	1.57	104.14	32.61	71.52	53.97
Pendimethalin + imazethapyr (1000 g/ha) PE	1.51	94.64	32.38	62.26	35.45	1.44	97.34	32.38	64.96	47.41
Weed free	1.53	96.56	46.35	50.21	23.40	1.58	104.76	46.35	58.41	40.86
Weedy check	0.93	57.68	30.87	26.81	0	0.71	48.42	30.87	17.55	0
LSD (p=0.05)	0.28	-	-	-	-	0.19	-	-	-	-

Yield and economics of cluster bean

Among herbicidal treatments, highest seed yield was recorded under pendmethalin 500 g + imazethapyr 50 g/ha (tank mixture) PE at both the locations that was statistically at par with imazethapyr + imazamox 70 g/ha at 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS, weed free treatment, imazethapyr 100 g/ha 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS and pemdimethalin + imazethapyr 1000 g/ha PE (**Table 2**). Among herbicides, the lowest number of pods/ plant, seeds/pod, biological yield and seed yield was observed with pendimethalin 1000 g/ha PE and imazethapyr + imazamox 43.7 g/ha at 3 WAS respectively. In the present study, higher net returns and increase over weedy check were recorded with pendimethalin 500 g + imazethapyr 50 g/ha (tank mixture) PE, imazethapyr 100 g/ha 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS, pendimethalin + imazethapyr (RM) 1000 g/ha PE at both the locations (**Table 2**). These results corroborate with the finding of Meena *et al.* (2011) where application of imazethapyr 100 g/ha significantly reduced the

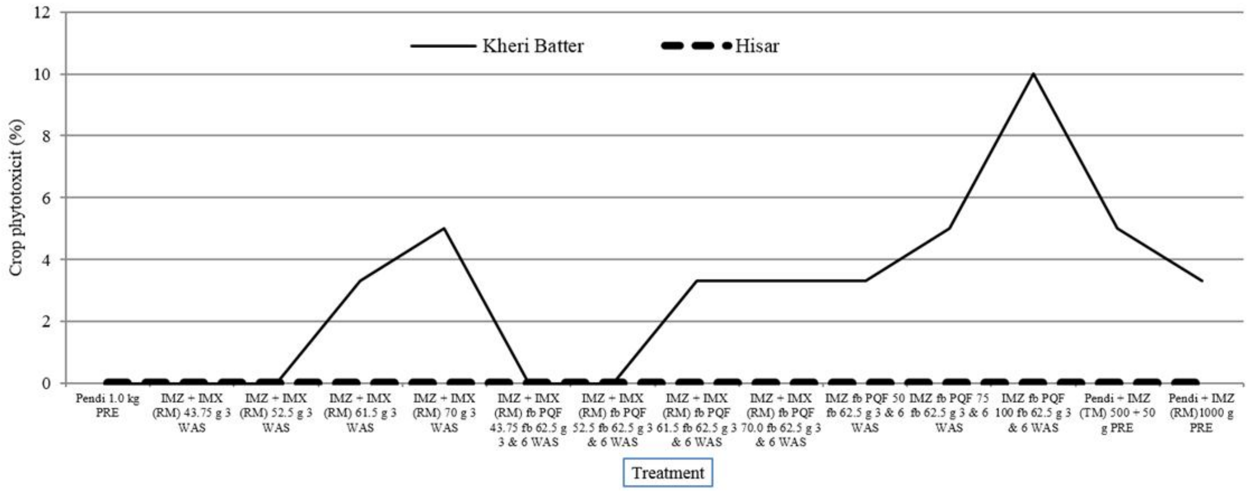

Figure 1. Phtotoxity of different herbicides applied in cluster bean on succeeding mustard crop at 2 weeks after sowing (WAS)

density of weeds and provided higher net returns and B:C ratio in soybean as compared to imazethapyr 150 g/ha or 50 g/ha.

Persistence of the herbicides applied in cluster bean may affect the yield of mustard in the next cropping season and persistence of imazethapyr at higher rate has been reported by farmers in sandy loam soil. But in the present experiment, crop suppression of 0-10 scale was observed under imazethapyr + imazamox 61.5 and 70 g/ha at 3 WAS applied alone and *fb* propaquizafop 62.5 g/ha at 6 WAS, imazethapyr 50, 75 and 100 g/ha 3 WAS *fb* propaquizafop 62.5 g/ha at 6 WAS, pendimethalin 500 g + imazethapyr 50 g/ha PE and pendimethalin + imazethapyr 1000 g/ha PE at farmer field (Kheri Batter) only due to light texture soil but the difference were non-significant, however there was no crop suppression observed under any treatment at 4 WAS and later stages, probably due to microbial degradation mediated by higher temperature (36.5^{O}C observed during the *Kharif* season 2013-14) or leaching of these herbicides because of heavy rainfall (500-580 mm) occurred between time of herbicide application and planting of mustard in 2013-14 (**Figure 1**).

From present study, it may be concluded that imidazolinone herbicides mixture and their sequential application were found effective in controlling weeds, increasing HEI (%) and net return in cluster bean under both the soil texture, but under sandy loam conditions imazethapyr + imazamox was less effective against predominance of existing weed *T. portulacastrum*.

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Sensitivity and terminal residues of various herbicides screened for the control of broomrape in tomato

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Herbicides

ABSTRACT

Sensitivity of sulfosulfuron, ethoxysulfuron, mesosulfuron + iodosulfuron (RM), glyphosate, metribuzin and imazethapyr against Himsona and Rocky hybrids of tomato and their residues in fruits and soil were evaluated in a field and screen house study during *Kharif* 2015 and 2016, respectively. Herbicides applied at different stages and doses caused injury to tomato seedlings in both hybrids up to 30 days after treatment (DAT). Phyto-toxicity was more prominent in case of mesosulfuron + iodosulfuron (RM) followed by ethoxysulfuron and glyphosate. Among both hybrids, herbicide toxicity was more in Rocky as compared to Himsona irrespective of dose and time of application. But crop recovered fully within 30 days in plots treated with sulfosulfuron at 25 g/ha either used as pre-plant incorporation (PPI) or pre-emergence (PE) and post emergence (PoE) applications of 25 g/ha twice on 15 and 45 DAT, respectively resulting in more number of fruits per plant and was on par with untreated check. For herbicides residues estimation, recovery experiments were performed by validation of analytical method at two fortification levels of 0.01 and 0.05 µg/g which gave average recoveries of different herbicides from 80.4 to 91.3%. The limit of detection (LOD) and limit of quantification (LOQ) of various herbicides were ranged from 0.003 to 0.01 µg/g. In tomato fruits, residues of these herbicides were below maximum residues limit (MRL) of 0.05 µg/g. Residues in soil ranged from 0.023 to 0.186 µg/g in various herbicide treatments. Sulfosulfuron application at 25 g/ha was found safe for *Orobanche* management in tomato.

INTRODUCTION

Broomrape (*Orobanche aegyptiaca)*, an annual parasitic weed is one of the major biotic constraints to tomato, cauliflower, cabbage, mustard, sunflower, tobacco, fababean and lentil crops which extract all nutrients, water and minerals from their host plants (Punia 2014, Punia and Duhan 2015). There have been reports of branched broomrape causing yield losses of up to 75% in tomatoes and 90% in rapeseed (Parker and Riches 1993, Eizenberg *et al*. 2004). In Haryana state, infestation of *O. aegyptiaca* locally known as Margoja/Rukhri/Khumbhi has been observed in tomato (*Lycopersicon esculentum* Mill) and mustard (*Brassica juncea* Czern and Cosson). During weed flora survey of tomato fields in 2014, the crop in Nuh, Ferozepur Jhirka, Nagina, Taoru areas of Mewat, Sahlawas of Jhajjar, Charkhi Dadri and Loharu of district Bhiwani was found seriously infested with this obnoxious weed threatening the cultivation of this crop in this region (Anonymous 2014).

The management of *Orobanche* is often difficult as it is closely associated with the host during its complete life cycle. Despite many management strategies like crop rotation and other mechanical weed control practices tried against broomrape, the use of selective herbicides were found most effective (Punia 2015, Punia and Duhan 2015). But, indiscriminate use of herbicides may lead to severe ecological consequences like residual carry over effects, destruction of natural enemy fauna, effect on non-target organisms, residues in food products and environmental factors like soil and water *etc*. Such treatments may suppress soil micro-flora and hence affect soil properties. Herbicides may have potential to bind to soil; the extent of which depends greatly on the nature of the chemical used. As per world trade organization (WTO) agreements, our agricultural produce must be free from pesticide residues, which can only be achieved through the application of modern production and protection logics. In order to avoid harmful effects of herbicides to mankind and ecosystem, top priority may be given to the use of low dose eco-friendly herbicides. Study of herbicides used for weed control and estimation of their bio-efficacy, phyto-toxicity, persistence behaviour, half-life period, safe waiting period in consumable products and environmental factors provide good interdisciplinary correlation between agriculture and residue chemistry.

Keeping in view, the present study was designed to know the sensitivity of Himsona and Rocky hybrids of tomato to three sulfonyl-urea herbicides *viz*. sulfosulfuron, ethoxysulfuron, meso + iodosulfuron (RM) and a phosphono-gylcine herbicide, glyphosate at different doses and time of applications. Selected doses of sulfosulfuron, ethoxysulfuron and glyphosate from field study were also evaluated in screen house along with two more herbicides- metribuzin and imazethapyr. The major objectives of this study was to evaluate these herbicides for their phyto-toxic effects on tomato hybrids before using best applications for effective control of *Orobanchae* infestation at farmers' field along-with estimation of herbicides residue in soil and tomato fruits.

MATERIALS AND METHODS

Field study

Tomato hybrids, Himsona and Rocky were planted in Vegetable Research Area of CCS Haryana Agricultural University Hisar, Haryana, India. Crop was raised as per university recommended package of practices for tomato except herbicide treatments in plots having 5.7 x 2.4 m size with factorial RBD design. The soil was sandy loam in texture with 65.5% sand, 18.1% silt and 16.3% clay, 0.4 EC $(dS/m)^2$, 7.6 pH and 0.35% organic carbon. There were 18 treatments having different application doses and time of applications (**Table 1** and **2**). All herbicides were sprayed by knap sack sprayer fitted with flat fan nozzle using 500 litres of water/ha. Observations on plant height and number of leaves per plant were recorded on 35 days after transplanting (DAT) while number of fruits per plant were recorded from five tagged plants at 90 DAT and averaged to compute values per plant. Tomato fruits picked in four flushes were weighed and thus total yield/ha was computed. These observations were subjected to ANOVA and means were compared with appropriate Fisher's protected LSD test at 5% level of significance. Crop phyto-toxicity due to different treatments was assessed at 30, 60 and 90 DAT on a scale of 0-10, where 0 means no injury and 10 means complete mortality of tomato plant. Foliar necrosis, yellowing, stunting and wilting were the main symptoms considered while making estimates of visual injury on tomato plants. Injury data were arc sine transformed prior to analysis but expressed in their original form also for clarity.

Screen house studies

In another experiment performed at screen house, only selected doses of sulfosulfuron, ethoxysulfuron and glyphosate as tested from field study along with two other herbicides metribuzin and imazethapyr were applied for only screening of herbicides sensitivity against the tomato crop. Seedlings of Himsona hybrid planted for field studies, were used for the pot experiment using plastic pots of 30 cm height and top diameter. Pots were filled with field soil mixed with vermi-compost (4:1 ratio by volume) and inoculated with *Orobanche* seed collected from affected tomato fields of Mewat area. Tomato seedlings were transplanted on 25 January - 2016 with three plants per pot. Herbicides, sulfosulfuron, metribuzin, imazethapyr, ethoxy-sulfuron and glyphosate were applied at different rates and time with three pots per treatment. PE application of sulfosulfuron (50 and 75 g/ha), metribuzin (125 and 250 g), imazethapyr (50 and 75 g) and ethoxysulfuron (50 and 75 g) were sprayed using backpack sprayer fitted with flat fan nozzles delivering a spray volume of 500 l/ha, before transplanting tomato seedlings. PoE application of the above herbicides and glyphosate (50 and 75 g/ha) was done at 30 DAT and 50 DAT for sequential sprays. Untreated control with and without *Orobanche* seed inoculation was maintained for comparison. Total 36 treatments were arranged in a CRD design in the screen house. Plants were watered as and when required. Since no emergence of *Orobanche* was observed, data on herbicide selectivity was recorded. Visual mortality (%) was recorded on 20, 35, 45 and 65 days after spray at 0-10 scale. Fruit number and yield was recorded six times from April to May and data was summed for fruits per plant and weight for ANOVA using SPSS. One way ANOVA was performed to separate effect of herbicides.

Herbicides residue study

The residue analysis was carried in the Agrochemicals Residues Testing Laboratory at Department of Agronomy, CCS Haryana Agricultural University, Hisar. Tomato and soil samples were collected in triplicate at crop maturity from experimental trial conducted for screening of different herbicides with two tomato hybrids.

Chemicals and reagents

The technical grade analytical standard of sulfosulfuron, ethoxysulfuron, mesosulfuron, iodosulfuron and glyphosate were procured from Fluka Sigma Aldrich, Germany. Other chemicals like acetonitrile (HPLC grade), analytical grade ammonium carbonate, sodium chloride, sodium sulfate (anhydrous), dichloromethane, ammonium hydroxide, methanol, HCl, phosphoric acid, triflouroacetic anhydride, triflouroethanol, ethyl acetate were purchased from Merck.

A standard stock solution of different sulfonyl-urea herbicides like sulfosulfuron, ethoxysulfuron, mesosulfuron and iodosulfuron were prepared in acetonitrile (HPLC grade). Standard stock solution of glyphosate was prepared in HPLC grade water (18 mΩ). The standard solutions required for constructing a calibration curve (0.003 to 1.0 µg/ml) were prepared from stock solution by serial dilutions with acetonitrile in case of different sulfonyl-urea herbicides and with HPLC grade water in case of glyphosate. All standard solutions were stored at 4°C before use.

Extraction and clean-up

Sulfosulfuron, ethoxysulfuron, meso + iodosulfuron (RM) were extracted by methods developed by Anjana *et al.* (2006) with slight modifications. For extraction of these herbicides fifty gram of the finely grinded, sieved soil and 25 g crushed tomato samples were taken in separate conical flasks and 50 ml of acetonitrile and ammonium carbonate mixture (9:1 v/v) was added to each flask. The flask was shacked for one hour on shaker and the content was filtered in another flask. The residues were again extracted with another 50 ml mixture of acetonitrile and ammonium carbonate (9:1 v/v). The content was again filtered in the same flask containing the first fraction. The combined content was concentrated on Heidolph rota-vapour to 20 ml at 40°C and was partitioned thrice (50, 30 and 20 ml) with dichloromethane after adding 20 ml of 10% brine solution. The combined dichloromethane extract was collected and passed through anhydrous sodium sulphate packed in a funnel so as to remove the moisture. Filtrate was collected, pooled and dried at 40°C on flash evaporator to near dryness. The residues were finally dissolved in 2 ml of HPLC grade acetonitrile and filtered through 0.45µm syringe filter before analysis on HPLC.

Extraction and clean-up of glyphosate from tomato and soil was achieved by the method of Hu *et al.* (2008). 50 g of dried and finely grinded sieved soil and 25 g of crushed tomato samples were taken in separate 250 ml conical flasks and extracted by shaking for one hour with 50 ml of 2M ammonium hydroxide. The process was repeated twice and the combined extract was taken in 250 ml of spherical flask. The content was evaporated to dryness at 75°C under vacuum. The sample was dissolved with 5 ml of water: methanol: HCl (160:40:2.7 v/v) thrice and collected in a centrifugal tube. The tube was kept at room temperature for one hour and than centrifuged at 5000 rpm for 15 min. The supernatant was transferred to a derivatization tube and blown to dryness with stream of nitrogen at 80°C. The tube was cooled to room temperature and was added with 1 ml of triflouroacetic anhydride (TFAA) and 0.5 ml of triflouroethane (TFE). The derivatization tube was kept in ice cooled water during this process. The content was then heated at 100°C on an oil bath for one hour. The excess reagents were removed by gentle stream of nitrogen again at 40°C. The content obtained after derivatization tube was transferred in a separatory funnel, 20 ml of water was added and partitioned thrice with 50 ml of dichloromethane each time and collected in a separate conical flask by passing through 2 cm bed of anhydrous sodium sulphate taken in funnel. The combined dichloro-methane content was dried over a rotary evaporator at 40°C. Finally the residues were reconstituted by dissolving in 2 ml of ethyl acetate, filtered through 0.45 µm syringe filter before analysis over GC-NPD.

Estimation

Analysis of the different herbicides mentioned above was carried using HPLC and GC-NPD. The instruments were tuned properly before injection of standard samples of all herbicides. Sulfosulfuron, ethoxysulfuron, meso + iodosulfuron (RM) were estimated by high performance liquid chromatography (HPLC) (Waters e-alliance 2695) having RP C-18 column (250 x 4.6 mm) and 5µ particle size. Acetonitrile: water (70:30 v/v) was used as mobile phase with an isocratic flow rate of 1 ml/min. Injection volume was maintained at 10 µl for each herbicide. Photodiode array detector (PDA, Waters 2998) was used at 254 µm for sulfosulfuron, 271 µm for ethoxysulfuron and 245 µm wavelengths for meso + iodosulfuron (RM) quantification. Retention time (Rt) of sulfosulfuron, ethoxysulfuron, mesosulfuron and iodosulfuron were 1.83, 1.79, 1.52 and 1.92 min, respectively. Glyphosate was analyzed on Shimadzu 2010 gas chromatograph (GC) equipped with capillary column, HP-I (30 m x 0.32 mm i.d. x 0.25 µm film thickness of film thickness of 5 per cent diphenyl and 95 percent dimethyl polysiloxane) and nitrogen phosphorous detector (NPD). Injection volume was 2 ml at split ratio of 1:5. The operating parameters of the instrument were: injection port was maintained at 270°C, column oven temperature ramping was started from 70°C (2 min) → at 25°C/min → 150°C (0 min) → at 15°C/min → 200°C (0 min) → at 8°C/min → 280°C (2 min), carrier gas was N_2 at flow rate of 1.8 ml/min, H_2 at 1.5 ml/min and zero air at 130 ml/min. Detector temperature was 280°C. Under these operating conditions, the retention time of glyphosate was found to be 14.61 min.

Calibration details, linearity check and validation of method

Different known concentrations of respective herbicides were prepared by diluting the stock solution as mentioned above and injected into the instruments for measuring the peak area resulting after elution of compound. A calibration curve was plotted for concentration of the standard injected versus area observed and the curve was found linear up to the lowest range from 0.003 to 1.0 µg/ml. The method for estimation of selected herbicides residues in tomato crop and soil using HPLC and GC-NPD was validated by performing recovery experiments. A representative 25 g of meshed tomato fruits and 50 g of soil sample was taken in 250 ml Erlenmeyer flasks and fortified at 0.01 and 0.05 µg/g spiking levels with standard solution of the selected herbicides mentioned above. These flasks were kept undisturbed overnight. On next day, extraction, clean-up and analysis were done according to the procedures mentioned above.

RESULTS AND DISCUSSION

Bio-efficacy and phyto-toxicity of herbicides under field conditions

Both tomato hybrids Himsona and Rocky responded differentially to herbicide doses and time of applications. Hybrid Rocky was more sensitive to sulfosulfuron, ethoxysulfuron and meso + iodosulfuron (RM) irrespective of dose and time of application as seen by visual crop injury to tomato seedlings (**Table 1** and **2**). Glyphosate at all doses was found more injurious to Himsona than Rocky. Ready mix combination of meso + iodosulfuron (RM) caused extreme toxicity to both tomato hybrids resulting in complete death of seedlings at 60 and 90 DAT. Although sulfosulfuron at 25 g/ha (PPI or PE) and its application twice at 25 and 25 g/ha at 15 and 45 DAT, caused mild toxicity in the form of leaf yellowing to the range of 9-11% in Himsona and 21-34% in Rocky, but crop recovered fully up-to 60 DAT reflecting no adverse effect on number of fruits/plant and fruit yield of tomato. Post emergence use of glyphosate at 25 g/ha (4 weeks after transplantation, WAT) although caused slight chlorosis and bleaching of leaves but crop recovered within 30 days of application with wrinkled leaves and lower number of tomato fruits and fruit weight in comparison to untreated check. Effect of herbicide treatments had significant effect on fruit yield of tomato. Maximum fruit yield 178.9 q/ha was obtained with use of sulfosulfuron (PE) at 25 g/ha which was significantly at par with sulfosulfuron 25 g/ha (PPI), untreated control and PoE application of sulfosulfuron at 25 g/ha at 15 and 45 DAT, respectively.

Bio-efficacy and phyto-toxicity of various herbicides under screen house studies

Metribuzin 250 g/ha was the safest treatment applied either PE or PoE (**Figure 1**). Even its higher dose (250 g/ha) or repeat applications of 125 and 250 g on 30 and 50 days caused minimum crop injury (<15%) when recorded 65 DAT. Application of sulfosulfuron 50 or 75 g/ha was more injurious when applied PE than PoE. Repeat applications of sulfosulfuron 50 followed by (*fb*) 50 g/ha or 75 g or 75 *fb* 75 g/ha at 30 and 50 days caused similar toxicity to that of single PE application and no significant variations in application rates were observed. Similar results were observed for ethoxysulfuron whereas, imazethapyr caused maximum crop damage. Application of glyphosate was less injurious than sulfosulfuron but affected the plant growth resulting in twisted leaves and affecting fruit size and weight.

Maximum tomato yield and fruit numbers were recorded with metribuzin 125 g/ha applied PE and non-sprayed plants followed by repeat application of ethoxysulfuron 75 *fb* 75 g/ha and metribuzin 125 g/ha applied at 30 DAT (**Figure 1**). Imazethapyr treated plants had no fruiting as there was complete plant mortality. Total fruit yield and fruit numbers were less with repeat applications of glyphosate compared to single application and also lower than other herbicides.

Herbicides residues study

The method for the estimation of selected herbicides residues in tomato crop and soil using HPLC or GC-NPD was validated by performing recovery experiments. Percent recoveries in all the samples of soil and tomato were found to be greater than 80%, so no recovery factor was needed for final calculations (**Table 3**). The harvest time residues status of different herbicides in tomato hybrids Himsona and Rocky and in soil under tomato crop has been presented in **Table 4**. It was observed that residues of sulfosulfuron in soil and both hybrids of tomato were below detectable level (BDL) at 25 g/ha

Table 1. Effect of different herbicide treatments on plant height and visual phyto-toxicity on tomato crop

Treatment	Crop phyto-toxicity (%) 30 DAT		60 DAT		90 DAT		Plant height (cms) 30 DAT	
	Himsona	Rocky	Himsona	Rocky	Himsona	Rocky	Himsona	Rocky
Sulfosulfuron (25 g/ha) PPI	19.4 (11.1)	29.7 (24.7)	0 (0)	0 (0)	0 (0)	0 (0)	21.2	20.6
Sulfosulfuron (25 g/ha) PE	17.8 (9.3)	27.7 (21.7)	0 (0)	0 (0)	0 (0)	0 (0)	23.0	21.3
Sulfosulfuron (25 and 25 g/ha) 15 and 45 DAT	17.9 (9.4)	28.2 (22.3)	0 (0))	0 (0)	0 (0)	0 (0)	21.8	21.1
Sulfosulfuron (50 and 50 g/ha) 15 and 45 DAT	18.4 (10.0)	28.8 (23.3)	0.0 (0.0)	22.6 (13.8)	18 (10.0)	25.3 (18.3)	21.5	20.0
Ethoxysulfuron (50 g/ha) PE	26.6 (20.0)	37.2 (36.7)	13.7 (8.3)	24.0 (17.5)	21.3 (13.3)	24 (16.7)	17.7	17.3
Ethoxysulfuron (50 and 50 g/ha) 15 and 30 DAT	29.9 (25.0)	33.2 (30.0)	21.3 (13.3)	26.6 (23.8)	15 (10.0)	33.1 (30.0)	20.1	18.5
Ethoxysulfuron (50 and 50 g/ha) PE and 45 DAT	35.2 (33.3)	52.7 (63.3)	39.2 (40.0)	59.0 (67.5)	46.9 (53.3)	55.1 (66.7)	17.3	17.0
Ethoxysulfuron (75 g/ha) PE	49.8 (58.3)	53.3 (64.3)	51.8 (61.7)	67.2 (76.3)	45 (50.0)	59.8 (73.3)	15.3	17.2
Ethoxysulfuron (75 and 75 g/ha) PE and 30 DAT	51.4 (61.1)	58.9 (73.3)	50.7 (60.0)	68.8 (77.5)	45.9 (51.7)	60.0 (73.3)	16.9	15.9
Meso+iodosulfuron (RM) (30 g/ha) PE	63.4 (80.0)	63.4 (80.0)	68.0 (85.0)	82.4 (83.8)	68.9 (86.7)	67.4 (78.3)	14.2	14.6
Meso+iodosulfuron (RM) (60 and 60 g/ha) PE and 45 DAT	65.8 (82.7)	67.4 (85.0)	90.0 (100)	90.0 (100)	90.0 (100)	90.0 (100)	12.1	14.0
Meso+iodosulfuron (RM) (90 and 90 g/ha) PE and 45 DAT	63.9 (80.0)	63.4 (80.0)	90.0 (100.0)	90.0 (100)	90.0 (100)	90.0 (100)	10.1	12.0
Glyphosate (25 g/ha) 4 WAT	0 (0)	0 (0)	6.1 (3.3)	0 (0)	0 (0)	0 (0)	19.4	20.8
Glyphosate (25 and 25 g/ha) 4 and 8 WAT	0 (0)	0 (0)	45.0 (50.0)	39.2 (40.0)	44 (48.3)	48.8 (56.7)	19.7	20.7
Glyphosate (50 g/ha) 4 WAT	25.9 (19.1)	26.6 (20.0)	40.1 (41.7)	39.2 (40.0)	49.3 (57.4)	49.8 (58.3)	19.7	20.2
Glyphosate (50 and 50 g/ha) 4 and 8 WAT	26.6 (20.0)	26.6 (20.0)	55.1 (66.7)	52.1 (61.5)	60.1 (75.0)	63.5 (80.0)	19.9	20.9
Glyphosate (25 and 50 g/ha) 4 and 8 WAT	18.4 (10.0)	18.4 (10.0)	50.8 (60.0)	54.8 (65.0)	49.8 (58.3)	50.8 (60.0)	19.9	21.2
Untreated check (control)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	22.4	22.2
LSD (p=0.05)	4.38	3.22	10.1	7.4	8.2	12.3	3.12	2.1

*PPI- Pre plant incorporation; DAT- Days after transplanting; PE- Pre-emergence; WAT: Weeks after transplantation
Original values are given in parenthesis which were transformed to arc sine transformation before analysis

Table 2. Effect of different herbicide treatments on number of leaves, number of fruits and fruit yield of tomato

Treatment	No. of leaves/plant (35 DAT)		No of fruits /plant (90 DAT)		Fruit field (t/ha)	
	Himsona	Rocky	Himsona	Rocky	Himsona	Rocky
Sulfosulfuron (25 g/ha) PPI	6.9	6.9	24.4	28.1	17.10	13.77
Sulfosulfuron (25 g/ha) PE	6.8	6.6	25.0	28.7	17.89	14.26
Sulfosulfuron (25 and 25 g/ha) 15 and 45 DAT	7.1	6.8	25.1	26.5	16.11	14.11
Sulfosulfuron (50 and 50 g/ha) 15 and 45 DAT	6.5	6.4	22.5	25.5	12.62	13.42
Ethoxysulfuron (50 g/ha) PE	4.5	4.4	21.2	15.4	10.34	10.19
Ethoxysulfuron (50 and 50 g/ha) 15 and 30 DAT	6.5	6.2	21.7	20.4	12.34	6.53
Ethoxysulfuron (50 and 50 g/ha) PE and 45 DAT	5.6	5.2	13.5	8.4	9.97	3.82
Ethoxysulfuron (75 g/ha) PE	5.3	5.3	10.4	5.3	4.64	3.50
Ethoxysulfuron (75 and 75 g/ha) PE and 30 DAT	4.9	4.9	13.7	9.1	4.51	2.74
Meso+iodosulfuron (RM) (30 g/ha) PE	3.1	3.1	5.9	13.9	1.97	2.98
Meso+iodosulfuron (RM) (60 and 60 g/ha) PE and 45 DAT	2.4	2.5	0.0	0.0	0	0
Meso+iodosulfuron (RM) (90 and 90 g/ha) PE and 45 DAT	1.8	1.8	0.0	0.0	0	0
Glyphosate (25 g/ha) 4 WAT	7.9	7.5	15.2	16.5	11.8	10.29
Glyphosate (25 and 25 g/ha) 4 and 8 WAT	6.9	7.0	11.8	13.7	6.37	6.17
Glyphosate (50 g/ha) 4 WAT	6.5	6.2	13.2	12.3	5.26	5.09
Glyphosate (50 and 50 g/ha) 4 and 8 WAT	6.1	6.0	6.4	7.6	2.56	1.84
Glyphosate (25 and 50 g/ha) 4 and 8 WAT	7.1	7.1	16.6	10.9	5.28	6.05
Untreated check (control)	7.6	7.5	26.8	32.2	15.75	14.54
LSD (p=0.05)	1.3	1.0	4.7	4.8	1.24	0.81

either applied PPI and PE. Residues of sulfosulfuron were not observed in fruits of both tomato hybrids with early post-emergence application at 25 g/ha on 15 DAT followed by its sequential use at same rate on 45 DAT. But residues to the level of 0.025 to 0.045 µg/g were observed in soil treated with PoE applications of sulfosulfuron.

Ethoxysulfuron, when applied at 50 g/ha at all applications *i.e.* PE and PoE (15 and 30 DAT) did not show any residues in tomato fruits of both hybrids. But in soil, residues of ethoxysulfuron at same application rates varied from 0.028 to 0.039 µg/g. Ethoxysulfuron applications at 50 and 75 g/ha as PE and 45 DAT showed 0.019 and 0.011 µg/g residues in

Table 3. Percent recovery of different herbicides in tomato and soil

Herbicides	Calibration parameter						Average* recovery (%)			
	Linearity check		Limits of analysis				Tomato		Soil	
			Tomato		Soil		Fortification levels		Fortification levels	
	Regression equation	R^2	LOD (µg/g)	LOQ (µg/g)	LOD (µg/g)	LOQ (µg/g)	(0.01 µg/g)	(0.05 µg/g)	(0.01 µg/g)	(0.05 µg/g)
Sulfosulfuron	77320x+443.9	0.995	0.007	0.01	0.005	0.008	81.92	88.95	91.30	81.27
Ethoxysulfuron	49494x+117.1	0.999	0.006	0.009	0.006	0.01	86.66	84.31	89.42	83.62
Mesosulfuron	46382x+23.45	1.0	0.008	0.01	0.005	0.009	83.24	80.44	87.32	82.24
Iodosulfuron	10033x+359.2	0.997	0.008	0.01	0.008	0.01	82.45	87.85	84.15	81.58
Glyphosate	10745x+47.88	0.998	0.005	0.01	0.003	0.006	84.22	83.94	86.40	84.45

*Average of three replicates

Table 4. Residues of different herbicides in tomato fruits (*var.* Himsona and Rocky) and soil

Treatment	Residues * (µg/g)			
	Tomato		Soil	
	Himsona	Rocky	Himsona	Rocky
Sulfosulfuron (25 g/ha) PPI	BDL	BDL	BDL	BDL
Sulfosulfuron (25 g/ha) PE	BDL	BDL	BDL	BDL
Sulfosulfuron (25 and 25 g/ha) 15 and 45 DAT	BDL	BDL	0.025	0.032
Sulfosulfuron (50 and 50 g/ha) 15 and 45 DAT	BDL	BDL	0.068	0.045
Ethoxysulfuron (50 g/ha) PE	BDL	BDL	0.034	0.028
Ethoxysulfuron (50 and 50 g/ha) 15 and 30 DAT	BDL	BDL	0.029	0.039
Ethoxysulfuron (50 and 50 g/ha) PE and 45 DAT	0.019	0.011	0.107	0.113
Ethoxysulfuron (75 g/ha) PE	BDL	BDL	0.062	0.045
Ethoxysulfuron (75 and 75 g/ha) PE and 30 DAT	0.022	0.018	0.070	0.086
Meso+iodosulfuron (RM) (30 g/ha) PE	BDL	BDL	0.033	0.023
Meso+iodosulfuron (RM) (60 and 60 g/ha) PE and 45 DAT	-	-	0.152	0.178
Meso+iodosulfuron (RM) (90 and 90 g/ha) PE and 45 DAT	-	-	0.166	0.186
Glyphosate (25 g/ha) 4 WAT	BDL	BDL	BDL	BDL
Glyphosate (25 and 25 g/ha) 4 and 8 WAT	BDL	BDL	BDL	BDL
Glyphosate (50 g/ha) 4 WAT	BDL	BDL	BDL	BDL
Glyphosate (50 and 50 g/ha) 4 and 8 WAT	BDL	BDL	0.075	0.061
Glyphosate (25 and 50 g/ha) 4 and 8 WAT	BDL	BDL	0.062	0.068
Untreated check (control)	BDL	BDL	BDL	BDL

*Average of three replicates; BDL (Below Detectable Level)

tomato fruits of both hybrids respectively and soil under both hybrids of tomato showed residues as 0.107 and 0.113 µg/g. The residues of ethoxysulfuron at application of 75 g/ha as PE and 30 DAT were found less in comparison to the residues at application rate of 50 g/ha at PE and 45 DAT. Meso + iodosulfuron (RM) herbicide at application rate of 30 g/ha did not accumulate in tomato fruits but showed little residue build up (0.033 and 0.023 µg/g) in soil. Meso + iodosulfuron (RM) at application rate of 60 and 90 g/ha on PE and 45 DAT, respectively completely killed tomato crop and hence no tomato fruits for residues analysis were available. But, in soil the residues of meso + iodosulfuron (RM) varied from 0.152 to 186 µg/g. It can be inferred from the above study that meso + iodosulfuron (RM) dissipation was slightly less in soil under tomato crop when compared with sulfosulfuron and ethoxysulfuron.

Residues of glyphosate at application rate of 25 g/ha at 4 and 8 WAT were not found in fruits as well as soil. Glyphosate, when applied at 25 and 50 g/ha at 4 and 8 WAT, respectively resulted in build up of residues in soil within range of 0.61 to 0.68 µg/g. This may be due to slow degradation of glyphosate in soil. Glyphosate have higher binding tendency to soil particles (Nomura and Hilton 1977, Reuppel *et al.* 1977, Newton 1984, Roy *et al.* 1989, Feng and Thompson 1990, Anton 1990) which prevents its leaching and runoff and hence greater persistence for longer duration. The glyphosate residues in tomato fruit of both varieties were found below detectable limit (BDL). It may be due to faster degradation of glyphosate in plant. The finding about fast degradation of glyphosate on foliage by Newton, 1984 further supported the results of present study in relation to prevention of glyphosate accumulation in fruits.

From the above study, it can be concluded that irrespective of dose and time of application, herbicides caused injury to tomato seedlings in both

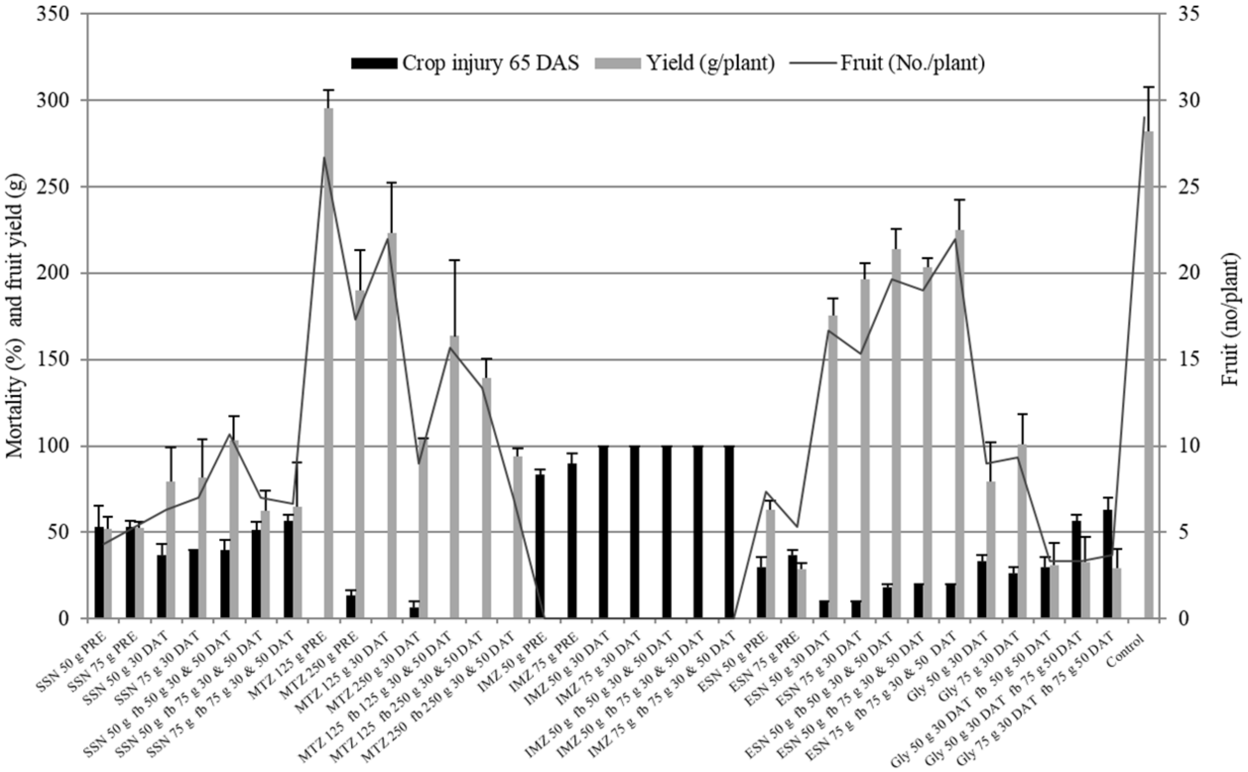

Figure 1. Effect of sulfosulfuron (SSN), metribuzin (MTZ), imazethapyr (IMZ), ethoxysulfuron (ESN) and glyphosate (Gly) on tomato mortality, fruit yield and fruit number per plant as observed in screen house study

Himsona and Rocky hybrids up to 30 DAT. Herbicide toxicity was more in Rocky as compared to Himsona irrespective of doses and time of applications. But crop recovered fully within 30 days in plots treated with sulfosulfuron at 25 g/ha either used as PPI or PE and its application at 25 g/ha twice on 15 and 45 DAT, respectively resulting in more number of fruits per plant and fruit yield was at par with untreated check. Sulfosulfuron when applied at 25 h/ha did not show any residues in tomato fruits and soil. In screen house study, ethoxysulfuron 75 *fb* 75 g/ha and metribuzin 125 g/ha applied 30 DAT were found safest treatment applied either PE or PoE. But, sulfosulfuron at 25 g/ha can be safely used in Himsona and Rocky hybrids of tomato for effective management of *Orobanchae*.

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Effect of time of sowing and weed management on weed incidence, productivity and profitability of *Bt* cotton

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ABSTRACT

A field experiment was conducted at Tamil Nadu Agricultural University, Coimbatore during winter seasons of 2015-16 and 2016-17 to evaluate the effect of time of sowing and weed management methods on *Bt* cotton hybrid. Different time of sowing and weed management methods play a significant role in determining weed incidence, crop growth and productivity of *Bt* cotton in Western Zone of Tamil Nadu. Results revealed that, early time sowing of *Bt* cotton on 1st August with pre-emergence application of pendimethalin 0.68 kg/ha followed by post-emergence application of pyrithiobac sodium 62.5 g/ha recorded significantly lower total weed density, dry weight and higher weed control efficiency with better performance of cotton growth, higher yield attributes, seed cotton yield and economics during both the years.

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is a heat loving crop; hence temperature imposes dramatic influence on cotton throughout the crop growth period. Extensive warming (by 4°C) in India could cause significant reduction in crop yields upto 25-40% in the absence of adaptation and carbon (C) fertilization (Rosenzeveig and Parry 1994). Climate change leads to rise in temperature and change in rainfall patterns which brings out a new threat to cotton productivity. Improper time of sowing influences the weed germination and weeds compete with cotton for the nutrients, moisture, light and space. *Bt* cotton hybrid are cultivated under wider plant/row spacing and heavily fertilized, which in turn invite multiple weed species infestation. Greater competition of weeds usually occurs early in the growing season. Early elimination of weeds might provide a favorable environment to the cotton through optimum time of sowing. Traditional non-chemical method of hand weeding effectively minimizes the weed competition and maximizes the yield of *Bt* cotton hybrid. However, hand weeding is a time consuming and labour intensive activity. Herbicides have greater role in managing weeds in cotton as well easy, as efficient and economical (Owen *et al*. 2015). Hence use of pre- and post-emergence herbicides at optimum time of sowing help to reduce the weed incidence and enhance the productivity and profitability of *Bt* cotton in Western Zone of Tamil Nadu.

MATERIALS AND METHODS

The experimental field is situated in Western Agro climatic zone of Tamil Nadu and located with 11°N latitude and 77° E longitude at an altitude of 426.7 m above mean sea level and the farm receives the normal total annual rainfall of 674.2 mm in 45.8 rainy days. Fields with uniform weed flora were selected for the experiment. Trial was conducted in sandy clay loam type of soil and it was medium in organic carbon content and the available nutrient status was low in nitrogen (191 kg/ha), medium in phosphorus (11 kg/ha) and high in potassium (449 kg/ha). The experimental fields were ploughed thrice and harrowed. The clods were broken and levelled with tractor drawn rotavator. Ridges and furrows were formed at 60 cm apart with ridge plough and at 90 cm apart for *Bt* cotton hybrid (Uttam BG II) and rectified manually. The recommended dose of 120:60:60 kg of N, P_2O_5 and K_2O per ha fertilizer was applied in the form of urea, single super phosphate and muriate of potash, respectively. Fifty per cent of N and K and full dose of P were applied as basal dose as band placement 5 cm away and 5 cm below the seed rows. The remaining 25% of N and 50% of K were applied at the time of square initiation [45 days after sowing (DAS) followed by with earthing up while 25% of N was applied during boll formation stage (75 DAS).

Experimental design and treatments

Field experiments were laid out in a split plot design with three replications. The treatments consisted of four dates of sowing *i.e.* 1st August (M_1), 15th August (M_2), 1st September (M_3) and 15th September (M_4) in the main plots and six weed management methods, *viz.* pre-emergence (PE) pendimethalin 38.7% CS 0.68 kg/ha followed by (*fb*) hand weeding at 40 DAS (S_1), PE pendimethalin 38.7% CS 0.68 kg/ha *fb* post-emergence (PoE) pyrithiobac-sodium 5% EC 62.5 g/ha (S_2), PE pendimethalin 38.7% CS 0.68 kg/ha *fb* PoE quizolofop-ethyl 5% EC 50 g/ha (S_3), PE pendimethalin 30% EC 1.0 kg/ha *fb* hand weeding at 40 DAS (S_4), two hand weeding on 20 and 40 DAS (S_5) and weedy check (S_6) were assigned in the sub-plots. PE herbicides were applied to the respective treatment plots at three days after sowing under adequate soil moisture condition and the PoE herbicides were sprayed as per the treatments plots at 25 DAS at 2-3 leaf stages of weeds. Hand operated knapsack sprayer fitted with a flat fan-type nozzle (WFN 40) was used for spraying the herbicides using a spray volume of 750 l/ha.

Total weed density and dry weight

Total weed density were counted using 0.5 × 0.5 m quadrat from four randomly fixed places in each plot and collected weeds were shade dried and later dried in hot-air oven at 80°C for 72 hrs. The weed density (no. /m^2) and dry weight (g/m^2) were recorded separately. Weed control efficiency (%) was calculated as per the procedure given by Mani *et al.* (2007).

$$\text{Weed control efficiency (\%)} = \frac{\text{WDc} - \text{WDt}}{\text{WDc}} \times 100$$

Whereas,

WDc: weed dry weight (g/m^2) in unweeded control plot

WDt: weed dry weight (g/m^2) in treated plot

Bio-physiological parameters

Measurement of photo synthetically active radiation (PAR), rate of photosynthesis, rate of transpiration and stomatal conductance were made on the top fully expanded leaf at different growth stages by Portable Photosynthetic System (PPS). These measurements were made between 10.00 am to 12.00 noon on all the sampling dates.

Statistical analysis

The data were statistically analysed following the procedure given by Gomez and Gomez (2010) for split plot design. The data pertaining to weeds were transformed to square root scale of $\sqrt{(X+2)}$ and analysed as suggested by Snedecor and Cochran (1967). Whenever significant difference existed, critical difference was constructed at 5 per cent probability level. Treatments where the differences are not significant are denoted as NS. Crop productivity was assessed correlated with weather factor of cropping periods through multiple linear regression model.

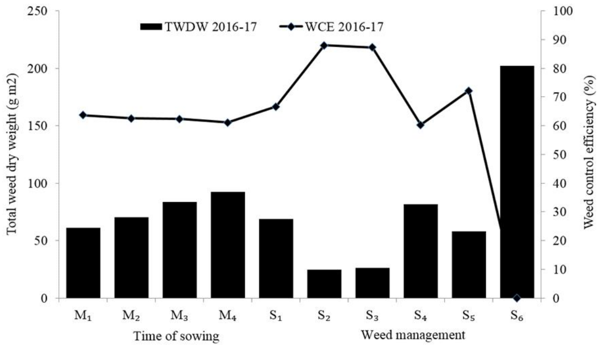
RESULTS AND DISCUSSION

Weed flora of the cotton experimental field was observed in weedy check plots at 40 DAS during the winter seasons of 2015-16 and 2016-17. Weed flora of the experimental field consisted of ten species of broad leaved weeds, five species of grasses and a sedge. Dominant among grassy weeds were *Echinochloa colona* and *Cynodon dactylon* whereas, *Trianthema portulacastrum* was the dominant broad-leaved weed during both the years of the experimentation. *Cyperus rotundus* was the only sedge present in the experimental fields.

Effect on weeds in *Bt* cotton

Distinct time of sowing showed effect on the weed growth in cotton fields during 2015-16 and 2016-17. Early sown cotton on 1st August recorded lower total weed density and dry weight and higher weed control efficiency as compared to delayed sown *Bt* cotton on 15th September. It might be due to better vigour of crop as a result of optimum time of sowing which subsequently suppress the weeds in due course. Similar results were earlier reported by Sharma *et al.* (2016) who had found that early sowing on 15th June had reported significantly higher weed control efficiency (60.5%) compared to 10th July sown crop (52.5%) at 60 DAS in direct seeded aromatic rice.

Pre-emergence (PE) application of pendimethalin at 0.68 kg/ha followed by post-emergence application (PoE) of pyrithiobac sodium 62.5 g/ha (S_2) recorded lower total weed density (48.0 and 47.2 no./m^2) (**Table 1**) weed dry weight (20.9 and 35.9 g/m^2) and higher weed control efficiency (80.2 and 86.2%) (**Figure 1**) at 40 and 60 DAS, respectively and was comparable with hand weeding twice on 20 and 40 DAS during 2015-16 and 2016-17. It is mainly due to sequential application of PE herbicides followed by PoE herbicides which could be attributed to weed free situation during initial stages and further control of new flushes of weeds by application of PoE herbicides at 2-3 leaf stage of



M_1 - 1st August; M_2 - 15th August; M_3 - 1st September; M_4 - 15th September
S_1 - Pendimethalin 0.68 kg/ha *fb* HW 40 DAS; S_2 - Pendimethalin 0.68 kg/ha *fb* pyrithiobac-Na 62.5 g/ha; S_3 - PE Pendimethalin 0.68 kg/ha *fb* quizolofob-ethyl 50 g/ha; S_4 - PE Pendimethalin 1.0 kg/ha *fb* HW 40 DAS; S_5 - Hand weeding twice on 20 and 40 DAS; S_6 - Weedy check

Figure 1. Effect of time of sowing and weed management methods on WCE (%) in cotton at 60 DAS

weeds and thus, reducing the weed competition during critical period of *Bt* cotton. The results are in corroboration with the findings of Hiremath *et al.* (2013) who had found that PE application of pendimethalin 38.7% CS 1.5 kg/ha *fb* PoE pyrithiobac-sodium 10% EC 0.125 kg/ha along with inter cultivation at 60 DAS registered the lower weed dry weight in *Bt* cotton.

Effect on nutrient removal by weeds in *Bt* cotton

Bt cotton sown on 1st August with PE pendimethalin 37.8 CS 0.68 kg/ha *fb* PoE pyrithibac-sodium 5% EC 62.5 g/ha recorded lower depletion of nitrogen, phosphorus and potassium removal which was comparable with hand weeding twice on 20 and 40 DAS. This might be due to lower weed density and dry weight recorded in this treatment. The total weed dry weight was another factor determining the nutrient removal by weeds (**Figure 1**). The findings are in line with the observations made by Jain *et al* (1981) who had reported that weed consumed 5 to 6 times nitrogen, 5 to 12 times phosphorus and 2 to 5 times potash more than cotton crop at the early growth stages and thus reduced seed cotton yield up to 54-85%.

During 2016-17, nutrients (nitrogen, phosphorus and potassium) depletion by weeds were lower in hand weeding twice at 20 and 40 DAS and comparable with PE pendimethalin 0.68 kg/ha *fb* PoE pyrithibac sodium 62.5 g/ha. This might be due to the weed-free environment created by the weed management method. This finding is in line with the report of Chander *et al.* (1994) who had inferred from his study that application of pendimethalin at 1.25 kg/ha followed by hand weeding reduced the nutrient depletion by weeds, which was comparable with hand weeding twice.

Effect on bio-physiological parameters in *Bt* cotton

Different time of sowing and weed management methods were significantly influenced the bio- physiological parameters of *Bt* cotton, ***viz.*** photo synthetically active radiation (PAR), rate of photosynthesis (Pn), rate of transpiration (E), stomatal conductance, vapour pressure deficit (VPD)

Table 1. Effect of time of sowing and weed management methods on total weed density, dry weight and weed control efficiency at 40 and 60 DAS in *Bt* cotton

Treatment	Total weed density no/m²) at 40 DAS		Total weed dry weight (g/m²) at 40 DAS		Total weed density (no/m²) at 60 DAS		Total weed dry weight (g/m²) at 60 DAS		WCE (%) at 40 DAS		WCE (%) at 60 DAS	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Time of sowing												
M_1	9.0(80.6)	10(102)	6.5(40)	7.9(61)	8.0(63)	9.5(89)	6.9(46)	8.0(62)	61.1	63.7	51.8	67.5
M_2	8.9(79.4)	10(102)	6.6(42)	8.5(70)	8.5(70)	9.7(91)	7.0(46)	8.3(66)	53.4	61.7	53.2	65.6
M_3	9.3(85.3)	11(110)	7.3(51)	9.3(84)	8.5(71)	10(101)	7.0(47)	8.8(75)	55.2	62.3	57.7	64.7
M_4	11(113)	11(121)	7.4(52)	9.7(92)	10(98)	10.3(104)	8.3(67)	9.1(80)	52.5	60.6	49.0	64.8
LSD (p=0.05)	0.37	0.43	0.29	0.36	0.45	0.32	0.37	0.24	-	-	-	-
Weed management methods												
S_1	7.3(53)	10(100)	5.8(32)	8.4(69)	7.6(56)	8.5(71)	6.4(39)	7.2(50)	69.0	63.5	64.3	75.8
S_2	7.0(48)	6.3(38)	4.8(21)	5.1(24)	7.0(47)	6.5(40)	6.2(36)	5.5(28)	80.2	88.6	67.4	86.2
S_3	7.1(50)	6.5(40)	5.4(27)	5.3(26)	7.9(60)	7.4(53)	6.4(39)	6.3(38)	73.8	87.4	64.8	81.7
S_4	7.7(59)	11(123)	6.5(40)	9.1(82)	8.7(73)	8.1(64)	6.9(46)	6.9(46)	60.5	58.4	58.5	77.8
S_5	11(122)	9.2(83)	7.4(53)	7.7(58)	7.6(56)	9.1(81)	6.5(40)	7.7(57)	49.8	65.9	62.6	72.2
S_6	14(205)	17(273)	10(104)	14(202)	13(157)	16(269)	10(109)	14(205)	0.0	0.0	0.0	0.0
LSD (p=0.05)	0.33	0.38	0.26	0.28	0.49	0.35	0.28	0.22	-	-	-	-
M x S	0.71	0.76	0.55	0.62	0.85	0.65	0.63	0.47	-	-	-	-
S x M	0.66	0.65	0.51	0.49	0.71	0.55	0.49	0.39	-	-	-	-

LSD, least significant difference at the 5% level of significance; the figures in the parentheses were original values

Table 2. Effect of time of sowing and weed management methods on bio-Physiological parameters at flowering stage of Bt cotton

Treatment	PAR (W/m^2)		Rate of photosynthesis (µmol /m^2 /sec)		Rate of transpiration (mmol /m^2/sec)		Stomatal conductance (mmol /m^2/sec)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Time of sowing								
M_1	1074	1098	22.6	22.1	5.6	6.0	100.4	99.5
M_2	1094	1078	20.9	21.4	5.6	5.9	99.5	96.1
M_3	1036	1035	18.3	20.5	5.0	5.3	97.3	93.3
M_4	982	975	17.3	19.6	4.9	4.8	86.3	92.8
LSD (p=0.05)	147	90	2.9	0.96	0.2	0.2	4.6	4.53
Weed management								
S_1	1070	1058	20.6	20.4	5.0	5.4	95.3	92.6
S_2	1101	1097	20.4	23.1	5.3	5.9	96.2	98.6
S_3	1009	1018	19.1	19.4	5.2	5.2	97.0	92.7
S_4	1030	1030	18.6	19.2	5.3	5.3	96.3	95.0
S_5	1094	1101	21.7	23.4	5.6	5.9	97.1	103.3
S_6	973	974	18.4	19.8	5.2	5.0	93.4	91.0
LSD (p=0.05)	109	89	1.8	0.9	0.2	0.2	2.4	6.2
S x M	NS	NS	NS	NS	NS	NS	NS	NS

Time of sowing	Weed management
M_1- 1st August	S_1- PE pendimethalin 38.7% CS 0.68 kg/ha *fb* hand weeding 40 DAS
M_2- 15th August	S_2- PE pendimethalin 38.7% CS 0.68 kg/ha *fb* POE pyrithiobac sodium 5% EC 62.5 g/ha
M_3-1st September	S_3- PE pendimethalin 38.7% CS 0.68 kg/ha *fb* POE quizalofob ethyl 5% EC 50 g/ha
M_4- 15th September	S_4- PE pendimethalin 30% EC 1.0 kg/ha *fb* hand weeding 40 DAS
	S_5- Hand weeding 20 and 40 DAS
	S_6 -Weedy check

and water use efficiency (**Table 2**) at all growth stages of cotton. Early sown cotton on 1st August recorded higher values of bio-physiological parameters and was comparable with cotton sown on 15th August during both the years of the experiments. According to Warner *et al*. (1995), diurnal carbon metabolism in cotton plants responds to night temperatures and diurnal temperatures and night temperatures affect the photosynthetic metabolism. Reduced sucrose transformation rate under cool temperature was consistent with the rate of photosynthesis in the late sown cotton (Liu *et al.* 2013).

Effect on yield parameters of *Bt* cotton

Higher number of sympodial branches with more number of bolls and boll weight were obtained in early sown *Bt* cotton on 1st August combined with PE pendimethalin 0.68 kg/ha *fb* PoE pyrithiobac sodium 62.5 g/ha and hand weeding twice on 20 and 40 DAS due to better control of weeds at critical stages and favourable environment for recording higher growth attributes of cotton leading to enhanced yield attributes. Many squares in the late planted cotton did not form bolls and planting date differences in final square number and boll numbers were due to a combination of temperature and early boll retention. The results are in corroboration with the findings of Liu *et al.* (2013) who have reported that late planting decreased boll number, boll weight, leaf area index, total biomass and harvest index but increased leaf to shoot, leaf to stem and leaf to boll ratios. Cool temperature increased specific leaf weight but decreased rate of photosynthesis and sucrose transformation rate in leaf subtending to cotton bolls. The increased bolls weight with the early sown crop could be attributed to the prevalence of optimum weather condition. Increased availability of solar radiation and bright sunshine hours might have increased the production of photosynthates and subsequent translocation to the bolls. Multiple regression equation revealed that growing degree days (GDDs) at flowering to boll development stage significantly influenced the boll weight.

Better growing condition with lesser weed competition in early sown cotton on 1st August with PE pendimethalin 0.68 kg/ha *fb* PoE pyrithiobac-sodium 62.5 g/ha resulted in higher number of sympodial branches (33.2 and 27.9), bolls (54.7 and 50.2) and boll weight (5.5 and 5.6 g/boll) with higher boll setting percentage of 54.3 and 53.3 (**Table 4**) during winter seasons of cotton 2015-16 and 2016-17, respectively. Similarly, early sown cotton on 1st August combined with hand weeding twice on 20 and 40 DAS also recorded with higher yield attributes**.** Results are in line with the earlier observations made by Madhu *et al*. (2014) who had found that the increased number of bolls/plant with bigger boll size were observed under sequential and /or combined use of PE and PoE herbicides with optimum time of sowing which might be due to lesser weed competition, which in turn might have allowed crop plants to grow better with proper utilization of available resources without competition by weed.

Yield prediction model of *Bt* cotton

Different time of sowing of *Bt* cotton had significant influence due to maximum and minimum temperature at various growth stages of *Bt* cotton. The coefficient of regression determination (R^2) was 0.98 in 2015-16 and 0.90 in 2016-17 (**Table 3**). Early sown cotton on 1st August received the maximum temperature of 30.5 - 32.6 ºC, 28.9 - 30.5 ºC and minimum temperature of 22.9 - 22.5 ºC, 21.3 - 21.2 in 2015-16 and 2016-17 respectively, which are the optimum for flowering and development stages that might have favoured better boll setting percentage and seed cotton yield. The results are in accordance with the findings of Yeates *et al.* (2013) who had concluded that flowers were damaged by low ambient minimum temperatures occurring near anthesis, which leading to shedding or lower seed number/boll which reduced boll size. The latter could be due to poor pollination and competition for assimilates. Shedding was correlated ($p < 0.01$) with minimum temperature at anthesis with less than 40% survival when minimum were below 6 ^{0}C.

Effect on productivity and profitably of *Bt* cotton

Early sown *Bt* cotton on 1st August recorded higher seed cotton yield (1.45 and 1.40 t/ha) than other dates of sowing during 2015-16 & 2016-17 (**Table 4**). There was a progressive reduction in seed cotton yield for every successive fortnightly shift in sowing dates from 15th August to 15th September in both the years of experimentation. Seed cotton yield was reduced drastically when the sowing was delayed beyond 15th August. It might be due to more GDDs (1314 and 1323 respectively in 2015-16 and 2016-17) in case of early sown *Bt* cotton on 1st August as compared to 1189 and 1212 GDDs in delayed sown cotton on 15th September. Optimum heat unit system with combined weather parameters facilitated cotton through higher photosynthesis, which might have led to higher sympodial branches, number of flowers, boll setting percentage, numbers of bolls/plant, boll weight and seed cotton yield as compared to late sown cotton hybrid. Buttar *et al.* (2010) also observed that under Punjab condition, higher yield parameters of symbodial branches, number of bolls and boll weight and seed cotton yield were registered in early sown American cotton *(G. hirsutum)* as compared to late sown.

During 2015-16 and 2016-17, the total rainfall received delayed sown cotton was 374, 237 and 337, 150 mm, respectively. Delayed sowing of cotton on 15th September registered lower seed cotton yield, due to heavy rainfall which coincided with the peak flowering period of cotton. During this period, the solar radiation and sunshine hours were also lesser and increased the boll shedding. The results corroborate with the findings of Ratnam *et al.* (2014) who had reported total rainfall over a range of 118.0 to 387.2 mm accounted for 68-74% of total variation in number of bolls and boll weight, respectively, over different sowing dates and seasons.

Advance sowing of cotton on 1st August with weed management practices of PE pendimethalin 0.68 kg/ha *fb* PoE pyrithiobac sodium 62.5 g/ha recorded maximum net return (Rs. 52340 and 38705/ ha) and B: C ratio (2.14 and 1.84). Whereas, minimum B: C ratio (1.15 and 1.13) was recorded in weedy check with delayed sowing of cotton on 15th September (**Table 4**) in both the years (2015-16 and 2016-17) of experimentation. It might be due to increased seed cotton yield due to least weed competition throughout growing season under the influence of sequential use of PE and PoE herbicides with one inter-culture operation with lesser cost of cultivation. The results are in line with the findings of Prabhu *et al.* (2012) and Hiremath *et al.* (2013), who had earlier reported that pre-emergence application of pendimethalin 38.7 CS 1.5 kg/ha *fb* pyrithiobac-sodium 10% EC 0.125 kg/ha with intercultvation at 60 DAS recorded higher seed cotton yield, gross and net returns of cotton.

Table 3. Regression models for studying the effect of maximum temperature and minimum temperature on seed cotton yield at various growth stages of winter irrigated *Bt* cotton

Parameters	Planting to emergence (X_1)	Emergence to first square (X_2)	Square to flowering (X_3)	Flowering to boll development (X_4)
2015-16				
Intercept	348.256	-3253.6	-1266.0	-3776.5**
Max T	-35.40**	71.283	126.69	-306.498
Min T	117.558**	302.3095	-69.81.	329.3**
(R^2)	0.98	0.63	0.65	0.98
2016-17				
Intercept	6467.00	-3955.07	-2792.10	3423.05**
Max T	326.92**	405.18	69.04	50.29**
Min T	-670.15**	-33.99	81.12	145.34
(R^2)	0.90	0.64	0.89	0.95

**Significant at 1% Probability *Significant at 5% Probability

Table 4. Effect of time of sowing and weed management on yield parameters, seed cotton yield and economics of *Bt.* cotton

Treatment	No. of sympodial branch/ plant		No. of bolls /plant		Boll setting percentage		Seed cotton yield (t/ha)		Net return (x103 `/ha)		BCR	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Time of sowing												
M_1	29.2	23.2	51.4	38.5	52.3	51.3	1.45	1.40	39.223	36.07	1.81	1.74
M_2	27.1	22.9	52.5	35.4	51.6	49.4	1.32	1.30	31.34	29.76	1.65	1.61
M_3	25.7	20.8	44.2	28.6	45.3	45.7	1.23	1.16	26.02	21.51	1.54	1.44
M_4	23.0	19.7	40.8	27.4	43.5	43.8	1.13	1.11	19.74	18.87	1.41	1.39
LSD (p=0.05)	1.5	1.0	3.0	1.8	3.2	3.2	0.11	0.09	-	-	-	-
Weed management												
S_1	27.5	23.1	47.9	35.1	47.9	47.0	1.30	1.27	28.30	26.77	1.57	1.54
S_2	29.8	26.4	55.2	43.2	49.7	48.7	1.64	1.41	52.34	38.70	2.14	1.84
S_3	27.9	20.6	46.6	31.8	48.2	47.4	1.26	1.22	29.83	27.28	1.65	1.60
S_4	27.9	22.8	46.9	30.9	48.6	47.1	1.19	1.25	21.08	24.79	1.42	1.49
S_5	30.3	26.4	63.3	40.4	51.4	49.6	1.52	1.51	36.71	36.26	1.68	1.67
S_6	14.1	10.5	23.2	14.2	43.2	45.5	0.80	0.78	6.21	5.49	1.15	1.13
LSD (p=0.05)	1.1	1.2	2.6	2.4	4.6	4.6	0.13	0.12	-	-	-	-
M x S	2.5	2.4	5.6	4.6	NS	NS	0.24	0.11	-	-	-	-
S x M	2.0	1.9	4.6	4.2	NS	NS	0.22	0.23	-	-	-	-

It could be concluded that early sowing of *Bt* cotton hybrid on 1st August in combination with sequential application of pendimethalin 38.7% CS as PE at 0.68 kg/ha followed by pyrithiobac-sodium as PoE at 62.5 g/ha enhanced productivity and profitability of winter irrigated cotton in Western Zone of Tamil Nadu.

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Herbicides performance for managing weeds in berseem under sub-mountainous conditions of Punjab

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ABSTRACT

A field experiment was conducted at farmer's field of district Gurdaspur during the winter seasons of 2014-15 and 2015-16 to assess the performance of various herbicides for managing weeds in berseem under sub-mountainous conditions of Punjab. The experiment was laid out in a randomized block design having three replications and comprised of eight treatments, *viz.* fluchloralin 0.45 kg/ha, pendimethalin 0.75 kg/ha, imazethapyr 0.075 kg/ha, oxyfluorfen 0.1 kg/ha, fluchloralin 0.45 kg/ha followed by (*fb*) imazethapyr 0.075 kg/ha, pendimethalin 0.75 kg/ha *fb* imazethapyr 0.075 kg/ha, oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha and a weedy check. All the weed control treatments caused significant reduction in weed density and biomass as compared to weedy check. The lowest weed density, weed biomass, maximum weed control efficiency, more number of tillers, maximum pooled green fodder and pooled seed yield and highest net returns were observed with fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha, which was closely followed by application of oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha.

INTRODUCTION

Berseem (*Trifolium alexandrinum* L.) is one of the prominent winter season forage crop grown in 1.9 mha area in India with a productivity of 60-110 t/ha (ICAR 2012). It is a fast growing annual legume which provides high quality green forage, rich in protein (15-25%), minerals (11-19% and carotene (Sharma and Murdia 1974). Berseem thrives well in a wide range of soils, though grows better in fertile (loamy to clay) soil with mild acidic to alkaline pH (6.5-8) conditions, possesses the ability for cold tolerance, short drought, flooding and mild tolerance to salinity. Being a winter season crop, several weeds infest into it. Common weeds found in berseem are *Cichorium intybus*, *Cornopus didimus*, *Spergula arvensis*, *Chenopodium album*, *Rumex dentatus*, *Melilotus indica*, *Medicago denticulata*, *Lathyrus aphaca* among broad-leaf weeds and *Phalaris minor*, *Polypogon monspeliensis* and *Poa annua* among the grassy weeds. These weeds not only deteriorate fodder quality but also decrease fodder yield (23-30%) and seed yield up to 50% (Joshi and Bhilare 2006, Alfred 2012). The contamination of produce with the weeds and weed seeds deteriorate the crop quality, if not controlled during critical period of crop-weed competition. Weeds decrease the acceptability of fodder and also pose problems in harvesting of the crop (Walia 2003). Due to several cuttings, it can suppress many weeds, but some weeds like *C. intybus*, *C. didymus* and *P. minor* survive and compete to reduce its growth and also lower the quality. *C. intybus* weed particularly found associated with berseem and gives more competitive stress and has lower protein content and is less palatable due to high silica content and crude fiber, thus adversely affecting the quality of berseem forage (Relwani 1979). Similarly, presence of *C. didymus* in the forage provides an offensive smell, which is repulsive to animals. Even, mechanical methods of weed control are very costly, labour intensive. As berseem is sown by broadcasting, manual weeding is not practicable in a dense crop. Hence, herbicides offer a better alternative to manual weeding. It is the major challenge to control the berseem weeds for enhancement of productivity and quality of fodder and seed yield. Hence, the current study was undertaken to evaluate different pre- and post-emergence herbicides and their combinations for their efficacy on weeds and crop selectivity in berseem.

MATERIALS AND METHODS

The field experiment was conducted at farmer's field of district Gurdaspur ($31^0$56` 43.4" N Latitude, $75^0$13` 39.5" E Longitude and 265.17 m Altitude from mean sea level) during two consecutive winter seasons 2014-15 and 2015-16 in the sub-mountaineous region of Punjab. The soil of experimental site was clay loam in texture, medium in organic carbon (0.72%), high in available phosphorus (35 kg/ha) and low in potassium (80 kg/ ha) at 0-15 cm soil depth. The soil was neutral in reaction (pH - 7.1) with normal electrical conductivity (0.61 ds/m). The experiment was laid out in a randomized block design having three replications and comprised of eight treatments, *viz.* fluchloralin 0.45 kg/ha, pendimethalin 0.75 kg/ha, imazethapyr 0.075 kg/ha, oxyfluorfen 0.1 kg/ha, fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha, pendimethalin 0.75 kg/ha *fb* imazethapyr 0.075 kg/ha, oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha and a weedy check. Berseem var. *'BL 10'* was sown at 20 kg/ha seed rate on 11th October and 9th October during 2014-15 and 2015-16, respectively. Seed was inoculated with *Rhizobium trifolii* and then broadcasted in standing water. The crop was fertilized with the recommended dose of fertilizer 25 kg N, 75 kg P_2O_5 per ha in the form of urea and single super phosphate, respectively. The first irrigation was given on 8th day after sowing (DAS). Afterwards it was applied within 8-10 days in summer and 10-15 days during winter and 30 days interval in spring. Overall 17 irrigations were applied to the crop. The herbicidal treatment fluchloralin 0.45 kg/ha was applied as pre-plant and sprayed on a well prepared seed bed just before sowing of berseem. The pre-emergence herbicide pendimethalin 0.75 kg/ha and oxyfluorfen 0.1 kg/ha were sprayed within 48 hours and seven days after sowing of berseem, respectively. Imazethapyr 0.075 kg/ha was applied as post-emergence at 20 DAS. Similarly, the pre-emergence herbicides followed by post-emergence herbicides were applied at their respective doses as per treatments. Herbicides were applied with manually operated knapsack sprayer fitted with flat-fan nozzle using 500 litres of water/ha. Four cuttings of fodder were taken during both the years of study, thereafter the crop was left for seed production and harvesting of seed was done on 10th June and 8th June during during 2014-15 and 2015-16, respectively. The data on weed density (number/ m^2) and biomass (g/m^2) were recorded at 55 days after sowing from each plot by using a quadrate measuring 1m^2. The weed density and biomass values were transformed to $(\sqrt{x+1})$ for statistical analysis. Weed control efficiency (WCE) (%) of different weedicides alone was also calculated as per the standard formula suggested by Gill and Vijaykumar 1969.

$$WCE = (DMC-DMT)/ DMC \times 100$$

Where, DMC is the weeds biomass in weedy check plots and DMT is the weeds biomass in a particular treatment.

The data on yield attributes, green fodder and seed yield of berseem crop were recorded at harvest. Economics was computed using the prevailing market price of inputs and outputs such as berseem green fodder at ` 1400/- per tonne while seed of berseem at ` 185000/- per tonne (Pooled price of two years). All data were analyzed statistically. Statistical analysis and interpretation of results were done by calculating values of C.D. (critical difference) at 5% level of probability through analysis of variance techniques as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed flora and weed control efficiency

The prominent weed species observed in the experimental field included *Cichorium intybus*, *Cornopus didimus*, *Spergula arvensis*, *Chenopodium album*, *Rumex dentatus*, *Melilotus indica*, *Medicago denticulata*, *Lathyrus aphaca* among broad-leaf weeds and *Phalaris minor*, *Polypogon monspeliensis* and *Poa annua* among the grassy weeds during both the years of study. The pooled data of two years indicated that weed infestation as referred in terms of total weed density and biomass were significantly affected by application of various pre-plant, pre-emergence and post-emergence herbicides. All the weed control treatments caused significant reduction in weed density and biomass as compared to weedy check. The lowest weed density (13.5 weeds/m^2) and biomass (10.2 g/m^2) were observed under fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha closely followed by application of oxyfluorfen 0.1 kg/ ha *fb* imazethapyr 0.075 kg/ha, which were significantly lower than all other herbicidal treatments (**Table 1**). The results were in conformity with the findings of Kumar and Shivadhar (2008). Pre-plant application of fluchloralin 0.45 kg/ha followed by post-emergence application of imazethapyr 0.075 kg/ ha recorded maximum weed control efficiency (82.8%), which was closely followed by the application of oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha (77.5%). Tiwana *et al.* (1985) observed successful control of *Poa annua* in Egyptian clover

Table 1. Effect of herbicide treatments on weed density and biomass in berseem (pooled data of 2014-15 and 2015-16)

Treatment	Weed density (no./ m^2)	Weed biomass (g/ m^2)	Weed control efficiency (%)
Fluchloralin 0.45 kg/ha	6.8 (45.4)	6.0 (35.3)	40.4
Pendimethalin 0.75 kg/ha	8.6 (72.5)	7.0 (48.5)	18.1
Imazethapyr 0.075 kg/ha	5.6 (30.9)	5.2 (26.2)	55.7
Oxyfluorfen 0.10 kg/ha	7.3 (52.6)	6.2 (37.1)	37.3
Fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha	3.8 (13.5)	3.3 (10.2)	82.8
Pendimethalin 0.75 kg/ha *fb* imazethapyr 0.075 kg/ha	5.1 (25.4)	5.1 (25.0)	57.8
Oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha	4.1 (16.0)	3.8 (13.3)	77.5
Weedy check	15.0 (224.8)	7.8 (59.2)	-
LSD (p=0.05)	0.8	0.7	-

Figures in parentheses indicate original values and data is transformed to $(\sqrt{x+1})$.

with fluchloralin. Weed control efficiency was highest with pendimethalin but it had toxic effect on the Egyptian clover. Prajapati *et al.* (2015) reported that weed biomass was significantly less due to application of pendimethalin 1.0 kg/ha *fb* imazethapyr 0.15 kg/ha. Singh (2012) reported that even after nine days of spraying isoproturon, oxyfluorfen and atrazine exhibited 77 to 100% crop injury. The lowest dose of pendimethalin (0.25 kg/ha) was also phototoxic to crop as it caused 90% injury 35 days after treatment which recovered to 70% by 60 days after treatment.

Effect on crop growth, green fodder and seed yield

The herbicidal treatments did not show significant effect on plant height of berseem at first cutting. Among the herbicidal treatments, fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha, being at par with oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha recorded significantly more number of tillers as compared to all other herbicidal treatments. This indicates that effective weed control might have created favourable environment for the development of tillers which led to increase in green fodder and seed yield. The maximum pooled green fodder (98.64 t/ha) and pooled seed yield (700 kg/ha) were recorded with fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha, which was closely followed by the application of oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha (**Table 2**). These results were in agreement with the findings of Pathan *et al.* (2013). However, pendimethalin 0.75 kg/ha *fb* imazethapyr 0.075 kg/ha and imazethapyr 0.075 kg/ha caused significant enhancement in green fodder and seed yield as compared to remaining herbicidal treatments. Significantly superior green fodder and seed yield were noticed under fluchloralin 0.45 kg/ha and oxyfluorfen 0.1 kg/ha as compared to the application of pendimethalin 0.75 kg/ha. Kumar *et al.* (2003) observed that fluchloralin 1.12 kg/ha gave significantly higher green fodder of berseem than pendimethalin 1.0-1.5 kg/ha. It may be inferred that weed free environment can facilitate better growth and crop development and ultimately through herbicides with higher berseem green forage and seed yield. These results are corroborating with the findings of Tamrakar *et al.* (2002) and Tiwana *et al.* (2002).

Economics

Owing to higher fodder and seed yield and timely management of weeds with the application of fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha resulted in attaining maximum net returns (` 1,98,856 /ha) and benefit: cost ratio (2.89) over all other weed control methods which was closely followed by oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha for obtaining net returns (` 1,95,151/ha) and and benefit: cost ratio (2.83) (**Table 3**). The minimum net return (` 1,18,951/ha) and benefit: cost ratio (1.79) was

Table 2. Effect of herbicide treatments on growth parameters and yield of berseem (pooled data of 2014-15 and 2015-16)

Treatment	Plant height (cm)	Tillers (no./m^2)	Green fodder yield (t/ha)			Seed yield (kg/ha)		
			2014-15	2015-16	Pooled mean	2014-15	2015-16	Pooled mean
Fluchloralin 0.45 kg/ha	86.5	761.2	83.83	86.54	85.19	544	569	556
Pendimethalin 0.75 kg/ha	84.1	723.6	73.53	75.97	74.75	469	512	491
Imazethapyr 0.075 kg/ha	87.1	788.9	89.12	91.34	90.23	600	627	614
Oxyfluorfen 0.1 kg/ha	86.7	756.7	82.05	85.18	83.62	531	559	545
Fluchloralin 0.45 kg/ha *fb* Imazethapyr 0.075 kg/ha	88.6	839.3	97.17	100.10	98.64	686	714	700
Pendimethalin 0.75 kg/ha *fb* Imazethapyr 0.075 kg/ha	85.3	796.8	90.60	92.53	91.57	613	631	622
Oxyfluorfen 0.1 kg/ha *fb* Imazethapyr 0.075 kg/ha	88.5	833.6	95.38	97.90	96.64	684	707	696
Weedy check	84.2	695.3	66.39	69.58	67.99	474	501	488
LSD (p=0.05)	NS	20.9	2.75	2.92	2.75	38	43	30

Table 3. Effect of herbicide treatments on economics of berseem (pooled data of 2014-15 and 2015-16)

Treatment	Gross returns ($x10^3$ `/ ha)	Cost of cultivation ($x10^3$ `/ ha)	Net returns ($x10^3$ `/ha)	B:C ratio
Fluchloralin 0.45 kg/ha	222.1	67.1	155.0	2.31
Pendimethalin 0.75 kg/ha	195.5	67.8	127.7	1.88
Imazethapyr 0.075 kg/ha	239.9	68.1	171.8	2.52
Oxyfluorfen 0.10 kg/ha	217.9	67.3	150.6	2.24
Fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha	267.6	68.7	198.9	2.89
Pendimethalin 0.75 kg/ha *fb* imazethapyr 0.075 kg/ha	243.3	69.4	173.9	2.51
Oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha	264.1	68.9	195.2	2.83
Weedy check	185.5	66.5	119.0	1.79

associated with weedy check. The lower crop yields in weedy check were the reasons for lower net return in this treatment.

Based on two years' data, it was concluded that application of fluchloralin 0.45 kg/ha *fb* imazethapyr 0.075 kg/ha closely followed by oxyfluorfen 0.1 kg/ha *fb* imazethapyr 0.075 kg/ha appeared to be productive and profitable for effective weed control in berseem which resulted in maximum green fodder and seed yield.

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Elevated CO_2 and temperature effect on growth and physiology of two *Physalis* species

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Open top chambers

ABSTRACT

Physalis minima L. and *Physalis peruviana* L. are the two important species in India which grow under wild, weedy or cultivated conditions. Fruits of these species are edible with high nutritional values and may be suitable for stuff for the production of new functional foods and drinks. Climate change has been reported to influences almost every aspects of agriculture. Rise in atmospheric CO_2 and temperature have been reckoned the two most significant variables involved in climate change. A study was conducted in open top chambers (OTCs) to understand the effect of elevated temperature (ambient + 2±0.5 ºC) and elevated CO_2 (550±50 ppm) individually and in combination on *P. minima* and *P. peruviana*. Study showed that elevated temperature as well as elevated CO_2 individually and in combination had positive effect on growth and development, rate of photosynthesis, and water use efficiency of both the *Physalis* species. Rate of transpiration and stomatal conductance increased marginally in plants grown at elevated temperature, but a marked decrease was evident at elevated CO_2 individually and in combination with elevated temperature as compared that in plants grown in ambient conditions in both the species. No significant changes were observed in relative water content and relative stress injury under any of the treatments in two species. Treatments- and species- specific changes were evident with respect to the activity of antioxidant enzymes and nitrate reductase, and peptide banding pattern using SDS-PAGE.

INTRODUCTION

Physalis minima is an abundant weed species in India commonly found in crops (*viz*. rice and soybean) as well as in non-cropped areas. The plant is an annual and can grow well in most soil types. It has broad leaves and grows rapidly on disturbed area, which makes it difficult to control. *Physalis peruviana* L. commonly known as 'goldenberry' or 'rasbhari' is considered mainly as weed but also being grown by some farmers on marginal lands. Utilization of wild/weedy species which are nutritionally sound, environmentally well adapted and acceptable to local population may go a long way in alleviating malnutrition and ensuring food security with dietary diversification (Pagare *et al.* 2016). *Physalis* species are nutrient-rich food sources traditionally grown and consumed by local communities in India and many other parts of Asia and Africa. Fruits of *Physalis* species are known to contain carbohydrates, lipids, minerals, vitamins, and phytosterols and â-carotene (Puente *et al.* 2011) and also have been reported to contain several active ingredients for curing diseases like cancer, leukemia, malaria, asthma, hepatitis, dermatitis and rheumatism (Joshi and Joshi 2015).

Climate change influences not only the performance of individual plant species but also can impact interactions with other species at different growth stages (Sarathambal *et al.* 2016). Rise in atmospheric CO_2 and temperature are two most important drivers involved in climate change (Ziska and George 2004). In addition to a thorough assessment of yield potential and nutritional aspects, domestication of a weedy/wild species also demands in depth studies of adaptive potential of such species towards stress and climatic conditions. During the present study, an effort has been made to assess the effect of climate change (elevated temperature and elevated CO_{2-}) on two *Physalis* species (*P. minima* and *P. peruviana*).

MATERIALS AND METHODS

This study was conducted in open top chambers (OTCs) at ICAR- Directorate of Weed Research, Jabalpur (23°102 N 79°562 E) Madhya Pradesh, India. Plants of the *Physalis* species (*P. minima* L. and *P. peruviana* L.) were grown in pots having 6 kg of soil and vermi-compost mixture (3:1 w/w). Treatments included ambient, elevated temperature (ambient + 2 °C), elevated CO_2 (550 ± 50 ppm), and elevated temperature + elevated CO_2. Elevated temperature was achieved through infrared heaters fitted inside the OTC chambers and precisely maintained with automatic control device through on/off mechanism by taking into account ambient temperature as reference at a given time. The desired temperature was maintained round the clock throughout the experiment. Elevated CO_2 treatment was maintained only during sunshine hours only. Different treatments were imposed from 10 days after sowing (DAS) till the end of the experiment. Sampling for different growth parameters was done at 30 and 60 days after treatments (DAT), while physiological and biochemical observations were taken at 60 DAT only. All the observations were made at least three times and analyzed using completely randomized design.

Leaves of plant were separated and total leaf area was measured using area meter (LI-3100C[R], Lincoln, Nebraska, USA). Shoot: root ratio was calculated from the data on dry weight of shoot and root. Growth rate was calculated as RGR (mg/plant/day) = $(W_2 - W_1)/(t_2 - t_1)$, where W_1 and W_2 are dry weights of aboveground parts of plant at time t_1 (30 DAT) and t_2 (60 DAT). Rates of photosynthesis, transpiration and stomatal conductance were measured using integrated portable photosynthesis system (LI-COR, LI-6400, Lincoln, NE, USA). All the observations were taken between 10.00 to 11.30 AM in second leaf from top.

For relative stress injury (RSI), leaf piece (5 cm^2) was washed with distilled water and then placed in a tube containing deionized water and kept at 27 °C for 6 h in diffused light. Then electrical conductivity (EC1) was recorded. Further, the same sample of leaf was again kept in a tube containing deionized water and autoclaved for 15 min to kill sample. After taking out the leaf, electrical conductivity (EC2) was measured at room temperature and RSI was calculated using the formula:

$$RSI = \frac{EC1}{EC2} \times 100$$

For relative water content (RWC), a piece (5 cm^2) was cut and weighed to obtain the fresh weight (FW). The turgid weight (TW) was recorded after keeping the leaves in deionized water for 4 h. Finally, samples were oven-dried at 60°C until constant weight was obtained and then the dry weight (DW) was recorded. The relative water content (RWC) was calculated using the following formula:

$$RWC = \frac{(FW-DW)}{(TW-DW)} \times 100$$

For biochemical observations, leaf samples were taken from second leaf from top and snap frozen in liquid nitrogen, and stored at -80 °C till further use. A 0.1 g of leaves were harvested and ground to a fine powder in liquid nitrogen. Ground powder was homogenized in 1.5 ml of cold phosphate buffer (100 mM, pH 7.0) containing 1% polyvinylpyrrolidone (PVP) and 1 mM EDTA and then centrifuged at 4 °C for 15 min at 10000g. The supernatant was separated and stored on ice till the assay of enzyme activity. This extract was used for the enzyme assay with spectrophotometer of all the enzymes except APX for which extraction buffer was supplemented with 2 mM L-ascorbate. Protein content of extract was determined using dye binding method.

Activity of catalase (EC 1.11.1.6) was determined by monitoring H_2O_2 removal as the decrease in absorbance at 240 nm as suggested by Aebi (1983). Enzyme extract (0.1 ml) was taken and to it, 1.0 ml of potassium phosphate buffer (50 mM, pH 7.0) was added. Reaction was initiated by adding 0.1 ml of 100 mM H_2O_2. The change in absorbance was recorded at 240 nm for 2 min. The enzyme activity was expressed as units/mg protein/min and a change of 0.1 absorbance corresponds to one unit of enzyme activity.

Ascorbate peroxidase (EC 1.11.1.11]) activity was determined by monitoring the oxidation of ascorbate according to the method suggested by Nakano and Asada (1981) with slight modification using reaction mixture consisting of enzyme extract (0.1 ml), 1.0 ml of potassium phosphate buffer (50 mM, pH 7.0) containing ascorbic acid (0.5 mM). The reaction was initiated by the addition of 0.1 ml of H_2O_2 (1 mM) and the decrease in absorbance was recorded at 290 nm for 2 min. The change of 0.1 absorbance corresponds to one unit of enzyme activity and enzyme activity was expressed as units/mg protein/min.

Guaiacol peroxidase (EC 1.11.1.7) activity was measured as suggested by Rao *et al.* (1996) using reaction mixture consisting of 0.1 ml enzyme extract, 1.0 ml 100 mM potassium phosphate buffer (pH 7.0) containing 1 mM EDTA, and 0.1 ml of 10 mM guaiacol. Reaction was started by adding and 0.1 ml of 10 mM H_2O_2. The increase in absorbance was recorded for 2 min at 470 nm and change of 0.1 absorbance has been taken as one unit and enzyme activity was expressed as units/mg protein/min.

Superoxide dismutase (EC 1.15.1.1) activity was estimated using xanthine-xanthine oxidase system as suggested by Beyer and Fridovich (1987). Enzyme extract (0.1 ml) was taken and to it 0.8 ml of 50 mM potassium phosphate buffer (pH 7.8), 0.05 ml NBT (2.24 mM), 0.1 unit of catalase (Sigma) and 0.1 unit of xanthine oxidase (Sigma) were added. Reaction was initiated by adding 0.05 ml of xanthine (2.36 mM) and change in absorbance was followed upto 2 min at 560 nm. A blank reaction was run using all the components but without sample extract to get the maximum intensity of colour. The enzyme activity was calculated as units (amountof enzyme required to inhibit NBT reduction by 50%) and expressed as units/mg protein/min.

Glutathione reductase (EC 1.11.1.9) activity was estimated by the method as suggested by Smith *et al.* (1988) in a reaction mixture consisting of 1.0ml 100 mM potassium phosphate buffer (pH 7.6), 0.1 ml enzyme extract, 0.05 ml 6 mM 5,5'-dithio-bis (2-nitrobenzoic acid) and 0.1 ml 0.2 mM oxidized glutathione. Reaction was initiated by addition of 0.05 ml of 5 mM NADPH. Change in absorbance at 412 nm was notedupto 2 min. The change of 0.1 absorbance is taken as one unit and enzyme activity was expressed as units/mg protein/min.

The *in vivo* assay of nitrate reductase (EC 1.7.1.2) in leaf was done according to the procedure of Jaworski (1971) with slight modifications as suggested by Ahmad *et al.* (2010). Fresh leaf tissue was cut into 1.0 cm^2 pieces and placed in ice-cold incubation medium containing 2.0 ml of 0.05M potassium phosphate buffer (pH-7.8) and 2.0 ml of 0.4M KNO_3 solution. The tubes were evacuated with a vacuum pump and then incubated in water bath at 28 ºC for 60 min under dark conditions. At the end of incubation period, tubes were kept in boiling water bath for 5 min to stop the enzyme activity and to allow complete leaching of the nitrite in the medium. Nitrite was estimated by the method of Evans and Nason (1953). An aliquot 0.1 ml of the reaction mixture was taken and 1.0 ml each of 1.0% sulphanilamide in 1N-HCl and 0.025% aqueous solution of N-(1-Napthyl)-ethylene di-ammonium dichloride were added. After 30 min, intensity of pink colour was measured by taking absorbance at 540 nm. Amount of nitrite was calculated using standard curve prepared using potassium nitrite solution. The enzyme activity was expressed as ìmole NO_2/mg protein/ min.

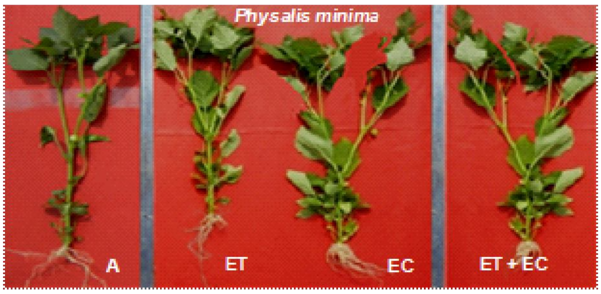
Changes in peptide profile of the leaves were determined by SDS-PAGE using discontinuous buffer system.

RESULTS AND DISCUSSION

Effect of elevated temperature and elevated CO_2 on growth and development

Growth and development of both the species (*P. minima* and *P. peruviana*) were affected in treatments and species-specific manner. Elevated temperature (ET) as well as elevated CO_2 (EC) individually and in combination (ET + EC) had positive effect on growth of both the species as compared that plants grown in ambient conditions (**Plate 1**).

Different growth parameters, *viz.* leaf area per plant, plant dry weight, shoot: root ratio and relative growth rate were assessed in two *Physalis* species at 30 and 60 DAT. Leaf area per plant increased marginally in plants grown under elevated temperature, elevated CO_2 individually and in combination as compared that in plants grown in ambient conditions in both the species and at both the



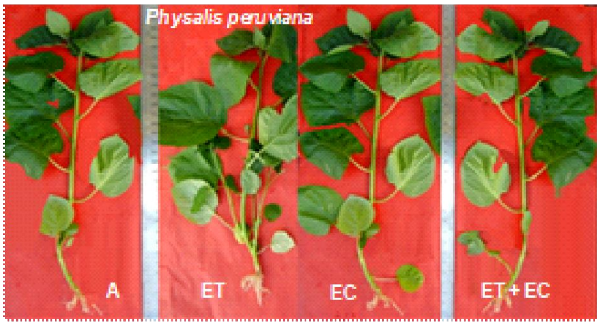


Plate 1. Effect of elevated temperature and elevated CO_2 on growth and development of two *Physalis* species at 60 DAT

sampling stages, however, difference was found to be non-significant. Significantly higher leaf area was noted in *P. peruviana* as compared to *P. minima* under ambient conditions as well under climate change conditions irrespective of sampling stages (**Table 1**). Similarly, plant dry weight also increased to some extent in plants grown under elevated temperature, elevated CO_2 individually and in combination as compared that in plants grown in ambient conditions in both the species and at both the sampling stages, however, again difference among the treatments was non-significant. Higher plant dry weight (almost 1.5 times) was recorded in *P. peruviana* as compared to *P. minima* under ambient conditions as well under climate change conditions at both the sampling stages (**Table 1**). Decrease in shoot: root ratio was evident in *P. minima* under elevated CO_2 alone or in combination of elevated temperature as compared to that under ambient conditions, however, no significant difference was observed at elevated temperature alone. On the other hand, no significant difference was observed in shoot: root ratio among the treatments in *P. peruviana*. Higher shoot: root ratio was observed in *P. minima* as compared to *P. peruviana* under ambient conditions as well under climate change conditions **(Table 1).** Relative growth rate (RGR) was calculated from the dry weights of above ground plants parts between 30 to 60 DAT. Only marginal differences in RGR was observed in plants grown under elevated temperature, elevated CO_2 individually and in combination as compared that in plants grown in ambient conditions. Significantly, higher RGR was recorded in *P. peruviana* as compared to *P. minima* under ambient conditions as well under climate change conditions (**Table 1**).

Enrichment of atmospheric CO_2 has been reported to increase growth of cucumber, tomato and lettuce. Plant growth is the direct effect of CO_2, which is beneficial for plants (Jablonski *et al.* 2002). It is expected that prolonged exposure of plants at increased atmospheric CO_2 concentration will enhance biomass (Poorter and Perez-Soba 2002). Yelle *et al.* (1990) observed that two weeks exposure of high CO_2 (900 ppm) resulted in 55 and 33% increase in leaf area and specific leaf weight, respectively, in tomato plants. Ziska (2003) studied the effect of elevated CO_2 on growth of six species namely *Cirsium arvense*, *Convolvulus arvensis*, *Euphorbia esula*, *Sonchus arvensis*, *Centaurea maculosa* and *Centaurea solstitialis*. Stimulation of plant biomass among species in response elevated CO_2 averaged 46%, with the largest response (+72%) observed for *Cirsium arvense*. Franzaring *et al*. (2008) conducted an experiment in *Brassica napus* in FACE system at elevated CO_2 and found that CO_2 enrichment had significantly increased plant height, shoot weight and dry weight of reproductive organs, indicating that plant development and the reallocation from vegetative to generative organs were sped up. It was also suggested that the plant phenology was generally more affected by elevated CO_2 during all growth stages (Lee 2011).

Table 1. Effect of elevated temperature and CO_2 on leaf area, plant dry weight, shoot: root ratio and relative growth rate (RGR) of *P. minima* and *P. peruviana*

Treatment	Leaf area (cm^2)		Plant dry weight (g/plant)		Shoot: Root		RGR (mg dry wt/plant/day)
	30 DAT	60 DAT	30 DAT	60 DAT	30 DAT	60 DAT	
Species							
P. minima	762^b	1674^b	10.4^b	22.2^b	16.0^a	14.8^a	391^b
P. peruviana	1482^a	3617^a	15.5^a	30.9^a	7.1^b	7.2^b	513^a
Climate change							
Control	1095^a	2579^b	12.0^c	25.4^c	12.6^a	12.1^a	447^a
Elevated temperature	1109^a	2651^{ab}	12.7^b	26.3^b	12.4^a	11.6^a	454^a
Elevated CO_2	1136^a	2668^a	13.2^b	26.9^a	10.7^b	10.1^b	459^a
Elevated temperature + elevated CO_2	1148^a	2684^a	13.9^a	27.4^a	10.8^b	10.0^b	450^a
Combinations							
P. minima × control	736^b	1575^b	9.6^c	21.0^d	18.1^a	17.0^a	378^b
P. minima × elevated temperature	748^b	1692^b	10.2^c	21.9^{cd}	17.5^{ab}	16.0^a	393^b
P. minima × elevated CO_2	781^b	1710^b	10.8^c	22.7^c	14.4^{bc}	13.1^b	398^b
P. minima × (elevated temperature + elevated CO_2)	785^b	1718^b	11.0c	22.9^c	14.2^c	13.0^b	397^b
P. peruviana × control	1455^a	3583^a	14.3^b	29.8^b	6.9^d	7.3^c	516^a
P. peruviana × elevated temperature	1471^a	3611^a	15.2^b	30.7^{ab}	7.1^d	7.2^c	516^a
P. peruviana × elevated CO_2	1492^a	3626^a	15.6^{ab}	31.2^a	7.0^d	7.1^c	519^a
P. peruviana × (elevated temperature + elevated CO_2)	1521^a	3650^a	16.8^a	31.9^a	7.3^d	7.0^c	502^a

DAT- Days after treatment; the values with same letter cases were not significantly different at $p \leq 0.05$ level.

The impact of these climate events has been documented in many crop species. Temperature is a major determinant in phonological development including flowering (Bahuguna and Jagadish 2015). Temperature and CO_2 together are expected to have significant impacts on key processes involved in physiology and phenology of plants. The beneficial effects of elevated CO_2 have been reported for many crops, however, it is also suggested that elevated temperature would counterbalance the beneficial effects of CO_2. Hence, the response of individual species to combinations of CO_2 and high temperatures is a critical research issue in order to work out impact of future climate change. Our results showed a slightly positive effect of elevated temperature and elevated CO_2 individually and in combination on different aspects of growth and development in two *Physalis* species.

Effect of elevated temperature and elevated CO_2 on physiological aspects

Rates of photosynthesis increased marginally in plants grown at elevated temperature and significantly at elevated CO_2 individually and in combination with elevated temperature as compared that in plants grown in ambient conditions in both the *Physalis* species. Significantly higher rates of photosynthesis were noticed in *P. peruviana* as compared to *P. minima* under ambient conditions as well under climate change conditions. However, increase in photosynthesis rates was more in *P. minima* as compared to that in *P. peruviana* under elevated CO_2 individually and in combination with elevated temperature (**Table 2**). Stomatal conductance is a measure of opening of stomata through which gas exchange takes place. In *P. minima*, a significant increase in stomatal conductance was noticed at elevated temperature; however, it decreased significantly at elevated CO_2 as compared to that under ambient conditions. A marginal increase in stomatal conductance was noticed in combination treatment (elevated temperature + elevated CO_2). Similarly, in *P. peruviana*, slight increase in stomatal conductance was observed at elevated temperature, while a significant decrease in stomatal conductance was evident at elevated CO_2 and elevated temperature + elevated CO_2 as compared to that under ambient conditions. In terms of absolute values, *P. peruviana* exhibited significantly higher stomatal conductance as compared to *P. minima* irrespective of treatments (**Table 2**). Rates of transpiration increased marginally in plants grown at elevated temperature, but a marked decrease in the rate of transpiration was evident at elevated CO_2 individually and in combination with elevated temperature as compared that in plants grown in ambient conditions in both the species. Decrease in transpiration rates was more in *P. minima* as compared to that in *P. peruviana* under elevated CO_2, however, in terms of absolute values; significantly higher rates of transpiration were recorded in *P. peruviana* as compared to *P. minima* under ambient conditions as well under climate change conditions (**Table 2**). Relative stress injury (RSI) is an indicator of membrane damage. Significantly higher values of RSI were noticed in *P. minima* in comparison to *P. peruviana*, however, no

Table 2. Effect of elevated temperature and CO_2 on photosynthesis, stomatal conductance, transpiration, RSI and RWC of *P. minima* and *P. peruviana*

Treatment	Photosynthesis (µmoles/m/s)	Stomatal conductance (m moles/m^2/s)	Transpiration (mmoles/m^2/s)	RSI (%)	RWC (%)
Species					
P. minima	14.8^b	115^b	4.6^b	18.4^a	81.5^a
P. peruviana	25.4^a	157^a	5.5^a	13.3^b	81.9^a
Climate change					
Control	16.8^d	140^b	5.6^a	15.6^b	82.1^a
Elevated temperature	18.6^c	154^a	5.8^a	17.1^a	81.1^a
Elevated CO_2	22.0^b	120^d	4.2^c	14.9^b	81.2^a
Elevated temperature + elevated CO_2	23.0^a	132^c	4.7^b	15.7^{ab}	82.3^a
Combinations					
P. minima × control	12.1^d	115^c	5.2^{cd}	18.0^a	81.7^a
P. minima × elevated temperature	13.8^d	130^{bc}	5.4^{bc}	19.5^a	80.7^a
P. minima × elevated CO_2	16.6^c	97^d	3.6^e	17.7^{ab}	82.4^a
P. minima × (elevated temperature + elevated CO_2)	16.8^c	119^c	4.4^d	18.3^a	81.3^a
P. peruviana × control	21.5^b	165^a	6.0^{ab}	13.4^c	82.6^a
P. peruviana × elevated temperature	23.4^b	177^a	6.2^a	14.6^{bc}	81.6^a
P. peruviana × elevated CO_2	27.4^a	143^b	4.1^{cd}	12.1^c	80.0^a
P. peruviana × (elevated temperature + elevated CO_2)	29.4^a	144^b	4.8^{cd}	13.0^c	83.4^a

The values with same letter cases are not significantly different at $p \leq 0.05$ level.

significant difference in RSI was observed in any of the treatments (**Table 2**). No significant difference in relative water content (RWC) of two *Physalis* species at 60 DAT was observed with respect to treatments and species.

Carbon dioxide, being a substrate for photosynthesis, may have direct effect on photosynthesis and other related gas exchange parameters. Exposure of C_3 plants to elevated CO_2 frequently results in an immediate increase in the rate of CO_2 assimilation (Leishman *et al.* 1999). In another study, Besford *et al.* (1990) found that photosynthesis of tomato leaves exposed to ambient and elevated CO_2 reached the same maximum value during leaf development, however, leaves of plants grown at elevated CO_2 developed more rapidly and exhibited maximum photosynthesis sooner. It was emphasized that increase and decrease in photosynthetic capacity depend on the stage of leaf development in tomato.

In agreement to our findings, decrease in stomatal conductance and transpiration has been reported by Morrison (1985) in both C_3 and C_4 species at elevated CO_2 and contention was further strengthened from significant increase in the transpiration efficiency (CO_2 assimilated per unit of H_2O transpired). Carlson and Bazaz (1980) reported that doubling the CO_2 concentration from 300 to 660 ppm resulted in an increase in water use efficiency in different species to a variable extent (5% in sunflower, 54% in corn, 48% in soybean). Oliva *et al.* (2002) studied the effect of elevated CO_2 (720 ppm) on plants of *Solanum curtilobum* and *S. tuberosum* grown in open top chambers and observed 55 to 59% reduction in stomatal conductance, however such a reduction did not limit the net photosynthetic rate, which was in fact increased by 53%. The transpiration rate was reduced by 16% in both the species while instantaneous water use efficiency increased by 80% in *S. tuberosum* and 90% in *S. curtilobum.* Plants grown under elevated CO_2 also showed 36 and 66% increment in total dry biomass, whereas yields (dry mass of tubers) were increased by 40 and 85 % in *S. tuberosum* and *S. curtilobum*, respectively. Two well documented responses of plants to elevated CO_2 are an increase in the rate of photosynthesis and a decrease in stomatal conductance (Unsworth and Hogsett 1996), and our results are in agreement to above report.

Effect of elevated temperature and elevated CO_2 on activity of enzymes

Effect of elevated temperature and elevated CO_2 individually and in combination was studied on the activity of important enzymes involved in antioxidant defence (catalase, ascorbate peroxidase, guaiacol peroxidase, superoxide dismutase and glutathione reductase) and nitrate reductase in the leaves of two *Physalis* species (*P. minima* and *P. peruviana*) at 60 DAT. In *P. minima*, a significant increase in catalase activity was recorded in plants grown at elevated temperature alone and in combination with elevated CO_2 as compared that in plants grown in ambient conditions, however, at elevated CO_2 alone, no significant deference was observed in catalase activity. In *P. peruviana*, increase in the activity of catalase was also evident at elevated temperature and in combination treatment (elevated temperature + elevated CO_2), while a decrease was observed at elevated CO_2. In terms of absolute values, higher activity of catalase was observed in *P. minima* as compared *P. peruviana* under climate change conditions, however under ambient conditions, higher activity was recorded in *P. peruviana* (**Table 3**).

Ascorbate peroxidase is another important enzyme of antioxidant defence pathway. In *P. minima*, ascorbate peroxidase activity decreased significantly in plants grown at elevated temperature and elevated CO_2 as compared to that in plants grown under ambient conditions. In *P. peruviana*, significant decrease in ascorbate peroxidase activity was noticed only at elevated CO_2. In terms of absolute values, not much difference was recorded in the activity of ascorbate peroxidase in two species. Guaiacol peroxidase activity decreased significantly in plants grown at elevated CO_2 and combination treatment (elevated temperature + elevated CO_2) as compared that in plants grown in ambient conditions in *P. minima*, however, in *P. peruviana*, significant decrease in guaiacol peroxidase activity was noticed only at elevated CO_2. No significant change in guaiacol peroxidase activity was observed at elevated temperature in either species. In terms of absolute values, higher activity of guaiacol peroxidase was recorded in *P. minima* as compared to *P. peruviana* under ambient conditions as well under climate change conditions.

Superoxide dismutase mediates the dismutation of superoxide radicals. Activity of superoxide dismutase increased significantly in plants grown at elevated temperature and combination treatment (elevated temperature + elevated CO_2) as compared that in plants grown in ambient conditions in *P. minima*. On the other hand, no significant change was observed in superoxide dismutase activity at different treatments in *P. peruviana*. In terms of absolute values, higher activity of superoxide dismutase was recorded in *P. peruviana* as compared to *P. minima* under ambient conditions as well under climate change conditions except at elevated temperature where activity of superoxide dismutase was almost similar in two species. No significant change in the activity of glutathione reductase was observed due to treatments in both the *Physalis* species, however, in terms of absolute values; higher activity of glutathione reductase was recorded in *P. peruviana* as compared to *P. minima* irrespective of treatments (**Table 3**).

Effects of elevated CO_2 concentrations on the antioxidant capacity and flavonoid content in strawberry fruits were studied under field conditions. Elevated CO_2 (300 and 600 ppm above ambient) concentrations resulted an increase in ascorbic acid, glutathione in strawberry. To determine whether elevated CO_2 reduces or exacerbates the detrimental effects of O_3 on aspen (*Populustremuloides* Michx.), aspen clones 216 and 271 (O_3 tolerant), and 259 (O_3 sensitive) were exposed to ambient levels of CO_2 and O_3 or elevated levels of CO_2, O_3 or CO_2+O_3 in the FACE facility and physiological and molecular responses were monitored and compared (Wustman *et al.* 2001). Antioxidant activities and phenylalanine ammonialyase (PAL) and 1-aminocyclopropane-1-carboxylic acid (ACC)-oxidase transcript levels showed a general increase in all O_3 treated clones, while remained low in CO_2 and CO_2+O_3 plants, which indicate that the ascorbate-glutathione and phenylpropanoid pathways were activated under ozone stress and suppressed during exposure to elevated CO_2. Our results also in agreement to the above findings as activity of most of the enzymes involved in antioxidants pathways decreased under elevated CO_2. McKee *et al.* (1995) suggested a protective role of elevated CO_2 against O_3 stress in matured flag leaves of wheat and advocated that protective effect of elevated CO_2 is mediated through decrease in stomatal conductance, which reduces O_3 influx received by the plant. High temperature-induced oxidative stress has been reported by many researchers (Larkindale and Knight 2002). In the present study, changes in different component of antioxidant defence pathway were evident under elevated temperature alone or in combination of elevated CO_2.

Nitrate reductase (NR) is a key enzyme in the nitrogen assimilation process. In *P. minima*, a significant increase in the activity of nitrate reductase was noticed in plants grown at elevated temperature, elevated CO_2 and combination treatment (elevated temperature + elevated CO_2) as compared to that in plants grown in ambient conditions. In *P. peruviana*, no significant change was observed in nitrate reductase activity at elevated temperature; however, significant increase in nitrate reductase activity was observed at elevated CO_2 and combination treatment as compared to that under ambient conditions. In terms of absolute values, higher activity of nitrate reductase was noticed in *P. peruviana* as compared to *P. minima* irrespective of treatments (**Table 3**). Geiger *et al.* (1999) suggested that higher rates of

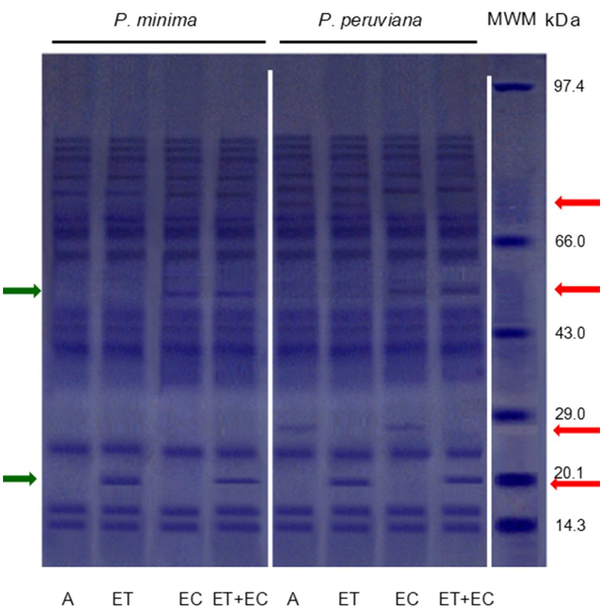
Table 3. Effect of elevated temperature and CO_2 on activity of catalase, ascorbate peroxidase, guaiacol peroxidase, superoxide dismutase, glutathione reductase and nitrate reductase (units/mg protein/min) of *P. minima* and *P. peruviana*

Treatment	Catalase	Ascorbate peroxidase	Guaiacol peroxidase	Superoxide dismutase	Glutathione reductase	Nitrate reductase
Species						
P. minima	4.5[a]	28.6[b]	13.1[a]	4.2[b]	5.5[b]	5.8[b]
P. peruviana	4.2[b]	31.0[a]	6.7[b]	5.4[a]	6.4[a]	16.4[a]
Climate change						
Control	3.7[c]	31.4[a]	11.3[a]	4.4[c]	6.0[a]	8.2[d]
Elevated temperature	5.3[a]	30.0[b]	11.5[a]	5.6[a]	6.3[a]	10.3[c]
Elevated CO_2	3.7[c]	27.5[c]	7.7[c]	4.4[c]	5.3[b]	12.9[b]
Elevated temperature + elevated CO_2	4.6[b]	30.3[b]	9.2[b]	4.9[b]	6.0[a]	13.0[a]
Combinations						
P. minima × control	3.5[e]	30.8[ab]	14.9[a]	3.3[d]	5.5[cde]	1.6[d]
P. minima × elevated temperature	5.7[a]	28.1[c]	15.0[a]	5.4[a]	5.9[abcd]	7.0[c]
P. minima × elevated CO_2	3.8[e]	25.7[d]	10.2[bc]	3.6[cd]	5.0[e]	7.2[c]
P. minima × (elevated temperature + elevated CO_2)	4.9[b]	29.9[bc]	12.4[b]	4.4[bc]	5.4[de]	7.5[c]
P. peruviana × control	4.0[cd]	31.9[a]	7.7[d]	5.5[a]	6.5[abc]	14.8[b]
P. peruviana × elevated temperature	4.8[b]	31.9[a]	7.9[cd]	5.7[a]	6.8[a]	13.6[b]
P. peruviana × elevated CO_2	3.7[de]	29.4[bc]	5.2[e]	5.2[ab]	5.7[bcde]	18.7[a]
P. peruviana × (elevated temperature + elevated CO_2)	4.1[c]	30.7[ab]	6.0[de]	5.3[a]	6.6[ab]	18.5[a]

The values with same letter cases are not significantly different at $p \leq 0.05$ level nitrate assimilation are required to support faster growth under elevated carbon dioxide. Similarly, increase in nitrate reductase activity under elevated CO_2 was observed in *Vigna radiata* (Sharma and Sengupta 1990). In agreement, our results also showed increase in nitrate reductase activity under elevated CO_2, temperature and combination of these two only in *P. minima*, while in *P. peruviana*, no such change was evident.

Effect of elevated temperature and elevated CO_2 on peptide profile (SDS-PAGE)

Peptide profiling using SDS-PAGE was performed in the leaves of two *Physalis* species grown under ambient condition, elevated temperature, elevated CO_2 and elevated temperature + elevated CO_2 at 60 DAT. A total of 16 bands could be visualized in *P. minima*, while in *P. peruviana*, 18 bands could be resolved. In of *P. minima*, 9^{th} band from top appeared only at elevated CO_2, and elevated temperature + elevated CO_2 and seems to be specific to elevated CO_2. Similarly, 14^{th} band from top appeared only at elevated temperature and elevated temperature + elevated $CO_2$and can considered specific to elevated temperature. In *P. peruviana*, 6^{th} band from top appeared under control conditions and at elevated temperature, but absent in other treatments indicating that this band disappeared whenever plants were exposed to elevated CO_2. Band number 10 from top appeared only at elevated CO_2, and elevated temperature + elevated CO_2 indicating that this band is specific to elevated CO_2. On the other hands, band number 16 from top appeared only at elevated temperature and elevated temperature + elevated CO_2indicating its specificity to elevated temperature. Band number 6 and 14 in *P. peruviana* seems to be species-specific (**Figure 1**).



MWM: molecular weight markers, A: ambient, ET: elevated temperature (ambient + 2 ºC), EC- Elevated CO_2 (550 ppm), ET + EC: elevated temperature + Elevated CO_2

Figure 1. Changes in peptide profile (SDS-PAGE) in two *Physalis* species (*P. minima* and *P. peruviana*) under elevated temperature and elevated CO_2. Arrows indicate position of differentially expressed peptides.

Protein is important macromolecule for any living organism. Till date, not much work has been done which can conclusively explain the extent and nature of the effects of elevated CO_2 on protein metabolism in plants. Meta-analysis techniques were used to examine the effect of elevated atmospheric CO_2 on the protein concentration of major food crops. Bokhari *et al*. (2007) studied proteomic response of rice seedling leaves to elevated CO_2 levels using 2-dimensional electrophoresis (2-DE). It was found that 57 spots showing differential expression patterns. Further analysis using MALDI-TOF/TOF-MS revealed that most of the proteins belonged to photosynthesis, carbon metabolism, and energy pathways. Several molecular chaperones and ascorbate peroxidase were also found to respond to higher CO_2 levels. Concomitant with the down regulation of photosynthesis and stomatal conductance, the levels of enzymes of the regeneration phase of the Calvin cycle were also decreased. Effects of elevated CO_2 (double of ambient) on soluble protein content and 2-dimensional electrophoretic pattern were studied in rice leaves grown in CO_2 controlled chambers (Fukayama *et al.* 2009). Soluble protein contents were slightly decreased in leaves grown under elevated CO_2, whereas the polypeptide profiles of soluble protein analyzed by 2-DE using the same amount of protein were totally unchanged between ambient and elevated CO_2.

In conclusion, *P. peruviana* was found to possess more resiliency against changes in climatic factors as compared to *P. minima*. Such attribute can be ascribed to higher relative growth rate and better inherent antioxidant potential under climate change regime.

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Parthenium, water hyacinth and *Medicago hispida* weed substrates effect on population, biomass of earthworm *Eisenia fetida* and yield of compost

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ABSTRACT

Farmers uproot plenty of weed biomass from their crop fields during weeding process and such biomass are generally thrown on the bunds and road side. Such weed biomass can be used for making vermicomoist to enrich crop soil. This study was done to see the effect of abundantly occurred weed biomass of *Parthenium*, water hyacinth and *M. hispida* as substrate on growth of earthworm *Eisenia fetida* and vermicompost yield. Increase in length and weight biomass of earthworms indicated that although *E. fetida* fed on all the three substrates provided to them, but most preferred weed species was *Medicago hispida* for the reproduction and development for the earthworm. The weight gained by total number of juveniles in different substrates indicated highest weight gain in the substrate of *M. hispida* (17.16 g/pot) followed by *Parthenium* (15.63 g/pot) and water hyacinth (13.21 g/pot). The number of cocoons recovered from which different substrates was highest in *M. hispida* and was statistically significant with other two substrates, while it was non-significant in *Parthenium* and water hyacinth. The maximum yield of vermicompost was obtained from *Parthenium* substrate (55.22%) followed by water hyacinth (46.05%) and *M. hispida* (45.22%). The vermicompost yield was not significantly different in water hyacinth and *M. hispida*, however, it was significantly different in case of *Parthenium*. Germination of *Parthenium* seedlings was recorded in vermicompost collected in form of the pellets of excreta individually from the vermicompost. This test unequivocally revealed that *Parthenium* seeds are not killed even if passed through the intestine of earthworm.

INTRODUCTION

India is a country of villages. Only about 30 years of excessive use of chemicals have caused devastating ecological implications on soil health. Organic farming is an alternative farming practice that may overcomes ill effects of fertilizers and pesticides by using natural materials and products. Organic agriculture is considered as a development vehicle for developing countries like India in particular and other countries in general because it requires less financial input and more reliance on the natural and human resources available (Ramesh *et al.* 2005). Due to continuous and large scale use of chemical fertilizers, fertility of land has been decreased gradually on sustainable basis. Therefore, bio-fertilizer like compost, vermincompost has become a boon to increase soil health. A huge amount of plant biomass is available in the form of weeds in the farmers' field itself. Proper utilization of these weeds can improve soil physical condition and environmental quality as well (Bhardwaj 1995, Verma and Kaur 2015). The recycling, reuse and resource recovery has been considered as one of the best options for waste management programme it is well documented that earthworm excreta has higher amounts of nutrients than that of the substrates or soil on which the earthworms feed. Moreover, the nutrients are changed to assimilable forms in the gut, that are more rapidly taken up by the plants (Gunadi and Edwards 2003, Baghel *et al.* 2005, Reddy *et al.* 2007).

We can make bio-fertilizer in the form of vermicompost from abundantly occurred biomass of weeds like *Saccharum munja* (Singh 2013), *Chenopodium murale* (Verma and kaur 2015), puncture wine *Tribulus terristris* (Kaur and Verma 2016) *etc.* Farmers uproot plenty of weed biomass from their crop fields during weeding process and such biomass are left generally in the field or thrown on the bunds and road side, which enrich the soil there only after decomposition. This uprooted weed biomass may be converted into compost or vermicompost. It is well documented that vermicompost is richer in macro and micro nutrients than compost simply prepared by the farmers in the form of a heap.

Weed biomass is one of the easily available sources of organic matter and plant nutrients, which hitherto, have not received required attention. The favourable climatic condition of India leads to the production of huge weed biomass of diverse species composition both in crop and non-cropped areas. The biomass production in weeds roughly ranges from 5-20 t/ha depending upon the weed species, season and growing conditions. *Parthenium hysterophorus* locally known as 'congress grass' or 'gajar ghas' is a dangerous alien invasive weed which is poisonous, pernicious, allergic and aggressive and poses a serious threat to human being and livestock. At present, it is one of the most troublesome and obnoxious weed of wasteland, forest, pasture, agriculture land and cause nuisance to mankind. The estimated biomass production of *Parthenium* is 5-8 t/ha/year (Sushilkumar and Varshney 2007, Sushilkumar 2014). Water hyacinth tops the list of all aquatic weeds and now spread to all around the country. It has successfully resisted all attempts of eradicating it by chemical, biological, mechanical, or preventive means. Water hyacinth from its native place of South America, Venezuela in particular, has now spread to over 50 countries around the earth. It is found in all types of aquatic bodies like ponds, lackes, dams, rivers, water channels and low lying area filled-up with the water. Many lacks in India were reported to be infested with water hyacinth. The estimated biomass production of water hyacinth is estimated about 7-12 ton/ha/year (Sushilkumar 2011). The weed *Medicago hispida* occurs in crop land during *Rabi* season, which may spread 30 inches in all direction from its centre crown and may reach 24 inches in height and contributes towards low yield of crops, such as wheat. The estimated biomass production of *M. hispida* is about 2-5 t/ha/year.

Earthworms are very important creatures of the earth for the maintenance of soil fertility and nutrient cycling besides promoting microbial activity in organic waste and break them down into materials, which can be used in crop production. This process also deals with management of agro-waste from various sources to generate useful products. Weeds uprooted during agricultural operation are also bio-waste, which can easily be recycled by the activity of the earthworms to produce a marketable biofertilizer in the form of 'vermicompost'. It is a good substitute for chemical fertilizers and has more NPK than normal heap manure and the compost prepared by NADEP methods and by other farmer practices (Sushilkumar *et al.* 2005).

Eisenia fetida, also known as red wrigglers, is the most common earthworms used for vermicomposting. The earthworm has been recognized as efficient bio-converters of organic residues in to high grade compost. Biomass production of *E. fetida* may attained an increase of 10-50 times in a period of 3-6 months, but it has been found to be regulated by availability of nutrients from substrate mixture. It is a potential organism for the management of organic waste (Tsukamoto and Watanabe 1977, Nauhauser *et al.* 1980). Gunadi and Edwards (2003) studied the effects of multiple applications of different organic wastes on the growth, fecundity and survival of *E. fetida* Edwards and Arancon (2004) has given emphasis of converting agro-waste and weed biomass with the help of earthworms in agriculture sector.

Considerable work has been carried out on the use of earthworms to recycle various organic wastes. However, there is not much published report available regarding the vermicomposting of weeds. In view of this lacuna and for better understanding of the process of vermicomposting from weed biomass, this study was done to see the effect of abundantly occurred weed biomass of *Parthenium*, water hyacinth and *M. hispida* as substrate for earthworm *Eisenia fetida* development and conversion of weed biomass to vermicompost.

MATERIALS AND METHODS

The experiment was undertaken during February to May 2012 at ICAR- Directorate of Weed Research, Jabalpur, comprised of three treatments with six replications. Three substrates of weed species namely *Parthenium hysterophorus, Eichhornia crassipes* and *Medicago hispida* were taken for study. Rag weed (*Parthenium hysterophorus*) and water hyacinth (*Eichhornia crassipes*) were collected from the road side and nearby pond, respectively, while *Medicago hispida* was collected from the farm of Directorate of Weed Research. The *Parthenium* plants were having flowers while *Medicago hispida* plants were having green seeds formation. Water hyacinth plants were not having flowers. The earthworms (*Eisenia fetida*) were obtained from vermicomposting unit of the Directorate for using in the experiment.

Weed biomass of different weed species was collected, chopped and heaped for about 30-35 days. Water was sprinkled at every two days till the biomass was half digested. Each pot having the size of 1.5×1×1 feet (depth × width × length) was filled up with seven kg of half-digested weed biomass of the respective weed species. In each pot, 50 earthworms after initial measurement for weight and length were released. The pots were kept in shady place and moisture of about 70-80% was maintained by sprinkling water as and when required.

Estimation of vermicompost yield: Earthworm castings were carefully removed periodically from the surface with the help of hard paper sheets and weighted for final vermicompost yield calculation. At the end of 95 days, the observations were stopped and all the vermicompost was removed and weighted. Vermicompost was carefully inspected for any cocoons and juveniles and if found, were counted for final calculation.

Estimation of earthworm growth parameters: All the earthworms including juveniles and cocoons were removed carefully and counted at 95 days. Observations were taken for mortality of adult earthworm, which were released initially in the pot. Each pre-released adult earthworm was again measured for its length and weight. Total number of juveniles per pot was counted and total weight per pot was taken for estimating increase in biomass of earthworm through reproduction.

Germination test for available *Parthenium* seeds: It was suspected that *Parthenium* seeds may be eaten by the earthworm along with weed humus because of its tiny size and plenty in numbers. This experiment was conducted to test whether the seeds of *Parthenium* may be passed through the intestine and may survive in the earthworm castings. To rule out the *Parthenium* seeds contamination from outside through air or by other means in the castings in the pots, well-formed biggest size castings were meticulously removed one by one from the freshly produce vermicompost with the help of forceps and kept in Petri-dishes for seed germination test in six replications. In each Petri-dish, 40 grams of castings were placed. Moisture was maintained and fortnightly observations were taken up to 45 days for *Parthenium* germination. After counting, seedlings were uprooted with the help of forceps. The vermicompost was again turn up and observations were taken for further germination.

Estimation of macro and micro nutrients from vermi-compost of different substratum: Organic carbon, phosphorus, nitrogen, pottasium and sulphur content were estimated by standard methods. Micronutrients (Cd, Fe, Cu) in the form of heavy metal were estimated from the vermicompost prepared from different substratum**.** An amount of each 0.5 g of vermicompost samples was digested using diacid solution (3:1) comprising of nitric acid and perchloric acid and the samples were filtered using Whatman no.1 filter paper and volume was made up to 100 ml in volumetric flask. The filtered samples were read for (cd, Fe, cu) using atomic absorption spectroscopy (THERMO S4).

Determination of vermicompost reaction (pH): pH of vermicopost was measured taking 5 g of vermicompost in a 100 ml beaker to which 50 ml of distilled water was added. The suspension was stirred well at regular in and pH was recorded with the help of pH metre.

Measurement of electrical conductivity: The clear extract after pH determination was used for electrical conductivity measurement. The conductivity of the supernatant liquid was determined with the help of salt (conductivity) bridge. The measurement of EC was adjusted (usually) at 25 ^{0}C for a known temperature of the solution by setting the knob provided for this purpose. The suspension was stirred well, just before the electrodes was immersed.

RESULTS AND DISCUSSION

Effect of weed substratum on population and biomass of earthworm

The initial average length and weight of each earthworm taken for study ranged between 8.70 to 8.84 cm and 0.92 to 0.95 g, respectively (**Table 1**). The average length and weight of each earthworm taken after 95 days of initial release ranged between 10.24 to 12.87 cm and 1.09 to 1.59 g, respectively. There was no significant difference in the average length and weight of earthworm fed on the substrates of *Parthenium hysterophorus* and *Eichhornia crassipes,* however there was significant difference in both the growth parameters of earthworm fed on the substrate of *Medicago hispida* (**Table 1)**. This increase in length and biomass indicated that although *E. foitida* fed on all the three substrates provided to them, but most preferred weed species was *Medicago hispida* for the reproduction and development of earthworm.

Mortality of earthworms in different substrates

The average total mortality of earthworm from initial 50 numbers was 3.0, 2.71 and 1.67 in substrates of *P. hysteroporus, E. crassipes* and *M.*

Table 1. Comparative growth parameters (average) of earthworms after 95 days of initial release

Weed substrate	Initial length (cm)	Initial weight (g)	Length after 95 days (cm)	Weight after 95 days (g)	No. of juveniles/pots after 95 days	Additional weight of juveniles/ pots	No. of cocoons/ pots	Mortality of initially released earth worm /substrate
Parthenium hysterophorus	8.71±0.08	0.95±0.02	10.4±0.07	1.09±0.01	509.3±32.0	15.6±0.72	84.8±9.28	3.0±0.89
Eichhornia crassipes	8.70±0.10	0.92±0.04	10.2±0.19	1.10±0.02	376.7±25.2	13.2±0.94	85.8±8.80	2.71±1.03
Medicago hispida	8.84±0.09	0.95±0.02	12.9±0.47	1.59±0.18	593.7±29.1	17.2±0.20	115.7±10.1	1.67±0.52
LSD (p=0.001)	0.11	0.13	0.36	0.13	35.58	1.03	11.58	1.03

hispida, respectively. Mortality of earthworm after 100 days was not found statistically significant (**Table 1**). Therefore, it can be inferred that mortality of earthworm may equally occur in all the substrates used in the study.

The weight gained by initially released earthworms and total number of juveniles in different substrates indicated highest weight gain in the substrate of *M. hispida* (17.16 g/pot) followed by *Parthenium* (15.63 g/pot) and water hyacinth (13.21 g/pot) (**Table 1, Figure 1**). This was statistically significant with each other.

Comparative development of juveniles and co-coons in three different substrates: Earthworms reproduced and produced juveniles and cocoons in all the substrates, but maximum number of average juveniles/pot were obtained from the substrates of *M. hispida* (593.7) followed by *Parthenium* (509.3/pot) and water hyacinth (376.7/pot).

The number of cocoons recovered from the different substrates were highest in *M. hispida* and

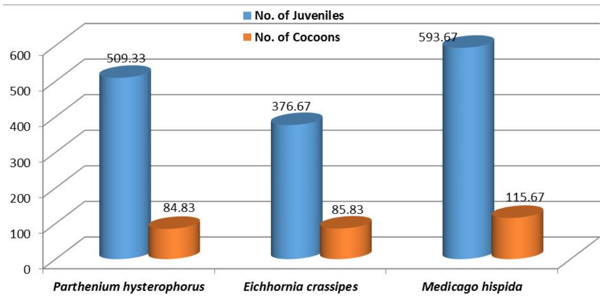

Figure 1. Juveniles and cocoons (in number) developed in different weed substratum after initial release

was statistically significant with other two substrates while it was non-significant in *Parthenium* and water hyacinth (**Figure 1**).

Yield of compost in different substrates: The maximum yield of compost was obtained from *Parthenium* substrate (55.22%) followed by water hyacinth (46.05%) and *M. hispida* (45.22%) (**Table 2**). The vermicompost yield was not significantly different in water hyacinth and *M. hispida*, however,

Table 2. Vermicompost yield (kg) after 95 days from 7 kg of weed substrats of each species

Weed substrat	Net yield (kg)	Unconverted weed substratum (gm)	%	Average conversion (%)	LSD (p=0.001)
Parthenium hysterophorus	3.43	783.3	55.2	55.2	
Echhorina crassipes	2.95	566.7	62.7	46.05	0.36
Medicago hipsida	3.11	137.55	45.3	45.22	

it was significantly different in case of *Parthenium*.

It was observed that maximum biomass of *M. hispida* (7.0 kg) was consumed by 80 days, but yield of vermicompost was significantly lower than the *Parthenium*, while maximum weed biomass of *Parthenium* and water hyacinth was converted into vermicompost by 95 days. It was interpreted that although *M. hispida* substrate was more palatable to earthworms and on this substrate, growth of earthworms was also high, but vermicompost yield was less in comparison to *Parthenium*. In *Parthenium*, the higher yield may be due to higher cellulose and fibre content. In *Parthenium*, cellulose content may be upto 42 to 47% (Jain *et al.* 2008).

Germination of seeds in *Parthenium* vermi-compost: Germination of *Parthenium* seedlings was recorded from the vermicompost collected from the heaps of the pots as well as from the pellets of excreta collected individually from the vermicompost. The germination of seeds was high during first week, which decreased gradually by second week. This test unequivocally revealed that *Parthenium* seeds are not killed even if passed through the intestine of earthworm. This study suggests that vermicomposting from *Parthenium* should be done before flowering to check further seed proliferation through application of vermicompost prepared from *Parthenium*.

Nutrients status in vermicompost prepared from different substrates: The nutrients status of N, P, K, S, Fe, Cu, Cd and EC and pH of vermicompost prepared from different substrates are given (**Table 3**).

Table 3. Nutrient status in vermicompost of different weed substrates

Type of weed substrate	N (%)	P (%)	S (%)	Fe (ppm)	Cu (ppm)	Cd (ppm)	EC (mS/cm)	pH (1:10)
Parthenium histerophorus	0.74	0.22	0.95	> 2144.99	30.86	ND	1.07	8.31
Medicago hipsida	1.91	1.17	1.05	> 2015.21	25.14	ND	0.61	7.49
Eichhornia crassipes	1.26	1.15	1.12	> 2077.58	33.73	ND	0.83	6.61

The total N ranged from 0.74 to 1.91%, maximum in *Medicago hispida* and minimum in *Parthenium*. The total P and S ranged from 0.22 to 1.17 and 0.95 to 1.12%, respectively. Maximum P was found in *M. hispida* followed by water hyacinth and *Parthenium*, while maximum S was recorded in water hyacinth followed by *M. hispida*. Cadmium could not be deducted in any samples in spite of the fact that water hyacinth was collected from a city ponds which was suspected to be rich in heavy metals and *Parthenium* from road side. Copper was high in water hyacinth followed by *Parthenium* and *M. hispida*.

Electrical conductivity (EC) and pH was recorded highest in *Parthenium* (1.07µs/cm and 8.31, respectively) while pH was towards acidic (6.61) in case of water hyacinth (**Table 3**).

This study revealed that reproduction and development of off springs may vary and depends on type of substrate provided to earthworms. In the present study, though there was highest increase in biomass, juveniles and cocoons number in *M. hispida* substrates, which was evidenced by the facts that all the biomass of 7 kg weeds was converted to vermicompost by 50 number of earthworms in 80 days, but total vermicompost yield by weight was significantly less than the *Parthenium* substrate where growth parameters were relatively less.

Verma and Kaur (2015) found significant variations in food preference in earthworm when the cattle dung was mixed with weed in different combination. Their study revealed that addition of weed in cow dung not only enhanced the growth of the worm but also increased cocoon production thus providing a possible tool towards proper utilization of weed for production of value added product. However, our study suggest that even effective utilization of weeds can be done to make vermicompost even without mixing of dungs.

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Pre- and post-emergence herbicides for weed control in blackgram

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ABSTRACT

Application of imazethapyr at all the rates of application (60, 75, 100 and 150 g/ha) significantly reduced the weed density and biomass as compared to quizalofop-ethyl followed by pendimethalin, alachlor and hand hoeing. Hand weeding superseded over all the treatments with the highest weed control efficiency of 96.5% followed by imazethapyr at 150 g/ha (71.9%), 100 g/ha (70.2%) and quizalofop-ethyl (70.3%). The post-emergence application of imazethapyr at 60, 75, 100 and 150 g/ha recorded significantly higher seed yield than pre emergence application of pendimethalin and alachlor and post emergence grass weed killer quizalofop-ethyl. The net monetary returns was maximum with hand weeding twice followed by imazethapyr at 150 g, 100 g and 75 g/ha. However, the benefit:cast ratio was the highest under imazethapyr at 75 g/ha followed by 100 g/ha

Blackgram (*Vigna mungo* L.) is an important crop among *Kharif* pulses of India and is usually grown in rainfed conditions on marginal and sub marginal lands. The crop contains about 25-26% proteins, carbohydrates 60%, Fat 1.5%, minerals, amino acids, and essential vitamins. In India, blackgram is grown in an area of 32.48 lakh hectares with the production and productivity of 21.99 lakh tonnes and 604 kg/ha, respectively during 2014-15 (Economic Survey 2014-15). In Madhya Pradesh, the crop covers an area of 8.62 lakh hectares with total production of 4.28 lakh tonnes and productivity of 496 kg/ha (Anonymous 2014-15). Weeds reduce the yield of blackgram to the extent of 78 % (Gogoi *et al.* 1992). Hand weeding is the common practice to control weeds in this crop (Chand *et al.* 2004). However, it is laborious, time consuming, costly and tedious. Furthermore, weather conditions do not permit timely hand weeding due to wet field conditions in rainy season. Thus, use of herbicides offer an alternative for effective control of weeds. The present experiment was undertaken to find out the efficacy of pre- and post-emergence herbicides for weed control in blackgram.

A field experiment was conducted at Research Farm, College of Agriculture, Tikamgarh, Madhya Pradesh, India during 2015 to evaluate the efficacy of pre- and post-emergence herbicides on weeds, yield attributes and yield of blackgram. The soil of the experimental area was clay loam in texture, medium in available N (290 kg/ha), medium in P_2O_5 (19 kg/ha) and K_2O (331 kg/ha) with pH 7.3. The experiment was laid out in a randomized block design and replicated thrice. Ten treatments consisted of pre-emergence application (PE) of pendimethalin at 1 kg/ha and alachlor at 1 kg/ha, post-emergence application (PoE) of imazethapyr at 60, 75, 100, 150 g/ha at 14 days after seeding (DAS), quizalofop-ethyl at 75 g/ha at 14 DAS, hand hoeing at 30 DAS, hand weeding at 20 and 40 DAS and weedy check. These treatments were replicated thrice in randomized block design.A uniform dose of fertilizer (20 kg N + 60 kg P_2O_5 + 20 kg K_2O/ha) was applied through urea, single super phosphate and muriate of potash, respectively, in all the plots. Variety AZAD-1 was sown with seed rate of 30 kg/ha at uniform row distance of 30 cm. Herbicides were applied using knapsack sprayer fitted with a flat-fan nozzle with water at 500 liter/ha. The data on weed density and biomass was recorded at 30 days after herbicide spray, and were were subjected to square root transformation "x+0.5 before analysis.

Effect on weeds

There was prevalence of monocot weeds in experimental field as these weeds constituted the higher relative density (77.2%) as compared to dicot weeds (22.7%). The dominant monocot weeds in the field were *Cyperus rotundus* (28.6%), *Echinochloa colona* (28.1%), *Cynodon dactylon* (12.7%) and *Commelina benghalensis* (7.7%) whereas among the dicot weeds,the intensity of *Digera arvensis* (L) was the highest (12.6%) followed by *Phyllanthus niruri* (L.) (11.1%) and *Corchorus olitorious* (L.) (10.6%). All the herbicidal treatments and hand weeding reduced the weed intensity as compared to weedy check (**Table 1**). Hand weeding twice was the most effective and recorded minimum weed density among all the treatments. Application of imazethapyr at all the rates of application (60, 75, 100 and 150 g/ha) significantly reduced the weed density and biomass and registered higher weed control efficiency as compared to quizalofop-ethyl followed by pendimethalin, alachlor and hand hoeing. Effective control of weeds with the application of imazethapyr was also reported by Rajput *et al.* (2014). Quizalofop-ethyl significantly reduced the density of grassy weeds, *viz. Cyperus rotundus*, *Echinocloa colonum* and *Cynodon dactylon* but was found ineffective against broad-leaved weeds, *viz. Commelina benghalensis*, *Digera arvensis*, *Phyllanthus niruri* and *Corchorus olitorius.* The herbicidal treatments and hand weeding significantly reduced the weed biomass compared to weedy check. Hand weeding superseded over all the treatments and attained minimum weed biomass (3.12 g/m^2) with the highest weed control efficiency of 96.5% followed by imazethapyr at 150 g/ha (71.9%), 100 g/ha (70.2%) and quizalofop-ethyl (70.3%).

Yield attributes and economics

Yield attributing characters, *viz.* number of pods/plant, number of seeds/pod and test weight attained significantly higher values under herbicidal treatments and hand weeding than weedy check (**Table 2**). Two hand weedings gave significantly higher number of pods/plant (36.33) and number of seeds/pod (8.13). The increase in yield attributes under hand weeding twice (20 and 40 DAS) was due to weed management from early crop growth and higher dry matter accumulation which resulted in

Table 1. Effect of pre- and post-emergence herbicides on weed density, biomass and weed control efficiency

Treatment	Time of application	Weed density (no./m^2)							Total weed density (no./m^2)	Total weed dry weight (g/m^2)	Weed control efficiency (%)
		Cyperus rotundus	*Echinocloa colona*	*Cynodon dactylon*	*Commelina benghalensis*	*Corchorus olitorius*	*Phyllanthus niruri*	*Euphorbia hirta*			
Imazethapyr at 60 g/ha	PoE at 14 DAS	4.63(21)	4.41(19)	4.59(21)	2.65(6.5)	1.6(2.1)	1.71(2.7)	0.73(0.0)	8.63(74)	5.08(25)	63.5
Imazethapyr at 75 g/ha	PoE at 14 DAS	4.49(20)	4.34(18)	4.45(19)	2.53(6.4)	1.22(1.0)	1.64(2.2)	0.71(0.0)	8.25(68)	4.98(24)	65.6
Imazethapyr at 100 g/ha	PoE at 14 DAS	4.30(18)	4.23(17)	4.38(19)	2.47(5.7)	1.10(0.7)	1.54(1.9)	0.71(0.0)	7.93(62)	4.75(22)	70.2
Imazethapyr at 150 g/ha	PoE at 14 DAS	4.24(17)	4.21(17)	4.26(18)	2.38(5.2)	0.92(0.4)	1.50(1.8)	0.71(0.0)	7.77(60)	4.69(22)	71.9
Pendimethalin at 1 kg/ha	PE	4.76(22)	4.83(23)	4.52(20)	3.25(10.1)	2.71(7.0)	2.95(8.2)	0.76(0.1)	9.62(92)	5.72(32)	32.3
Alachlor at 1 kg/ha	PE	5.20(27)	5.25(27)	4.77(22)	3.36(10.9)	3.15(9.4)	3.05(8.9)	0.71(0.0)	10.4(107)	6.32(39)	23.3
Quizalofop-ethyl at 75 g/ha	PoE at 14 DAS	3.24(11)	3.08(9)	2.30(5)	3.80(14.0)	3.13(9.3)	3.61(12.7)	2.09(3.9)	8.79(77)	4.72(22)	70.3
Hand hoeing	30 DAS	7.77(60)	8.49(72)	5.24(27)	4.23(17.4)	3.29(10.3)	3.73(13.4)	2.17(4.2)	14.8(219)	8.63(75)	29.3
Hand weeding	20 and 40 DAS	2.29(5)	1.58(2)	1.97(3)	1.44(1.7)	0.98(0.5)	0.88(0.3)	0.71(0.0)	3.63(13)	1.97(3)	96.5
Weedy check		7.83(61)	8.27(73)	5.27(27)	4.36(18.7)	3.13(9.5)	3.42(11.3)	2.34(5.0)	15.0(225)	8.25(68)	0
LSD (p=0.05)		0.83	1.73	0.53	0.7	0.56	0.59	0.17	1.03	1.08	

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

Table 2. Effect of pre and post emergence herbicides on yield attributes, seed yield and economics of blackgram

Treatment	Time of application	No. of pods/ plant	No. of seeds/ pod	Seed weight/ pod	Test weight (g)	Seed yield (kg/ha)	Weed index (%)	Net monetary return (x10^3 `/ha)	B:C ratio
Imazethapyr at 60 g/ha	Post-emergence at 14 DAS	31.0	7.00	0.26	36.8	1042	26.0	32.52	3.24
Imazethapyr at 75 g/ha	Post-emergence at 14 DAS	31.5	7.07	0.27	37.0	1104	21.5	34.84	3.41
Imazethapyr at 100 g/ha	Post-emergence at 14 DAS	31.5	7.27	0.28	37.3	1118	20.6	35.09	3.33
Imazethapyr at 150 g/ha	Post-emergence at 14 DAS	32.3	7.35	0.28	37.5	1136	19.3	35.22	3.16
Pendimethalin at 1 kg/ha	Pre-emergence	28.1	6.40	0.24	36.3	845	40.0	24.04	2.29
Alachlor at 1 kg/ha	Pre-emergence	26.3	5.93	0.23	35.8	818	41.9	23.70	2.43
Quizalofop-ethyl at 75 g/ha	Post-emergence at 14 DAS	28.7	6.07	0.23	36.0	913	35.2	26.75	2.53
Hand hoeing	30 DAS	23.8	5.80	0.22	34.0	772	45.1	20.69	1.90
Two hand weeding	20 and 40 DAS	36.3	8.13	0.31	38.5	1410	0	42.65	2.90
Weedy check		21.3	4.93	0.19	33.3	656	53.3	17.89	1.99
LSD (p=0.05)		4.29	0.88	0.04	0.76	94.5			

greater translocation of food materials to the reproductive parts and reflected in superiority of yield attributing characters and ultimately to higher yield (Nirala *et al*. 2016). Among the herbicidal treatments, imazethapyr as post-emergence recorded significantly higher number of pods/plant and number of seeds/pod than pre-emergence application of alachlor, post-emergence application of quizalofop-ethyl and hand hoeing at 30 DAS. All the herbicidal treatments were significantly superior over weedy check.

Seed yield was significantly higher under all the weed control treatments over weedy check. Two hand weeding at 20 and 40 DAS recorded the highest seed yield (1410 kg/ha) followed by imazethapyr at all the rates of application. Post-emergence application of imazethapyr at 75, 100 and 150 g/ha (1104, 1118 and 1154, respectively) was found at par with respect to seed yield. All the rates of application of imazethapyr recorded significantly higher seed yield over pre-emergence application of pendimethalin (799 kg/ha), alachlor (818 kg/ha) and post-emergence grass weed killer quizalofop-ethyl (913 kg/ha). Application of quizalofop-ethyl proved significantly effective in producing higher seed yield over one hand hoeing (722 kg/ha), pre-emergence application of pendimethalin (799 kg/ha) and alachlor (818 kg/ha). Aggarwal *et al*. (2014) also reported the effectiveness of imazethapyr for controlling weeds in blackgram.

The highest gross and net monetary returns was obtained with two hand weeding followed by imazethapyr at 150, 100 and 75 g/ha but the benefit: cost ratio was the highest with imazethapyr at 75 g/ha followed by 100 g/ha.

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Weed management effect on weeds, crop, nutrients uptake and soil physico-chemical properties in blackgram

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ABSTRACT

Field experiment was conducted during *Kharif* season 2015-16 at N.D. University of Agriculture and Technology, Kumarganj, Faizabad, (UP) to asses the weed management effect on weeds, crop, nutrients uptake and soil properties in black gram. The result of the investigation revealed that application of imazethapyr + imazamox 80 g/ha PE was found superior in controlling weeds, increasing blackgram yield and nutrient uptake and recorded maximum benefit: cost ratio. Next best treatments were pendimethalin 1000 g/ha and metribuzin 200 g/ha PE.

Weeds are the major threat in harnessing the full potential of applied and native plant nutrients as they remove considerable amount of nutrients and adversely affect the yield of the leguminous crops which have greater requirement of phosphorus for symbiotic nitrogen fixation (Kumar *et al.* 2015). Blackgram (*Vigna mungo* L.) is less competitive against many weeds during early stage of the crop and the most sensitive period of crop weed competition is between 15 to 45 days after sowing. Herbicides *e.g.* imazamox and imazethapyr individually as well as in ready mixed combination have been tried in various pulse crops and found convincing results. Information on weed management practices on nutrient uptake and soil fertility in blackgram is meagre, hence, the present investigation was undertaken.

The field experiment was conducted during *Kharif* season 2015-16 at N.D. University of Agriculture and Technology, Kumarganj, Faizabad (UP) with 10 treatments in there replications. The soil of the experimental field was silt loam in texture having pH 8.1 low in available nitrogen (125 kg/ha) and medium in available phosphorus (15 kg/ha) and potash (240.5 kg/ha). The pre-emergence herbicides were applied in soil on next day of sowing, while post-emergence spray was done at 3-4 leaf stage (20 DAS). Soil and plant samples were collected from each plot for soil and plant parameter studies by using standard methods.

Effect on weed density, growth, yield and economics

At 60 days after seeding (DAS), highest weed density was recorded in weedy check and lowest under in imazethapyr + imazamox (RM) at 80 g/ha PE treatment, which was significantly superior with other treatments. This might be due to its better solubility and effectiveness. Similar result was also reported by Meena *et al.* (2011). At 60 DAS, taller plant was recorded with pre-emergence application of imazethapyr + imazamox (RM) 80 g/ha PE (42.25 cm), which was at par with two hand weeding (40.65 cm) and significantly better than other treatments. Minimum plant height was recorded (25.60 cm) in weedy check plot. Application of different type of herbicides like pre-emergence and post-emergence influenced the number of nodules per plant at 60 DAS of crop growth. At 60 DAS, imazethapyr + imazamox (RM) 80 g/ha PRE application significantly increased the number of nodules per plant (37.96) as compared to rest of the treatments, however, it was at par with hand weeding (36.96) at 60 DAS. Highest dry weight of nodules (30.45 mg) was recorded under T_3 treatment, which was at par with hand weeding, metribuzin at 200 g/ha PE and pendimethalin at 1000 g/ha PE (29.60, 28.24 and 28.73 mg), respectively but significantly superior to rest of the treatments.

The maximum grain yield (1.21 t/ha) of blackgram was recorded with imazethapyr + imazamox (RM) at 70 g/ha PE, which was at par with hand weeding (1.19 t/ha), pendimethalin at 1000 g/ha

Table 1. Effect of weed management practices on weed density, growth, yield and economics of blackgram

Treatment	Total weed density (m^2) at 60 DAS	Plant height (cm) at 60 DAS	No. of nodules/ plant at 60 DAS	Dry weight of nodules/plant (g) at 60 DAS	Grain yield (t/ha)	B:C ratio (` Re-invested)
Imazethapyrat 70 g/ha PE	12.63 (159.2)	37.10	30.10	24.10	1.02	1.95
Imazethapyrat 80 g/ha PE	12.00 (143.7)	38.75	33.55	26.85	1.09	2.11
Imazethapyr + imazamox (RM) at 70 g/ha PE	9.91 (97.8)	42.25	37.96	30.45	1.21	2.29
Metribuzin at 200 g/ha PE	11.17 (124.6)	39.85	35.25	28.24	1.13	2.18
Pendimethalin at 1000 g/ha PE	11.31 (127.6)	40.28	35.90	28.73	1.13	2.17
Imazethapyrat 70 g/ha PoE	14.50 (209.9)	36.77	27.45	21.98	0.99	1.84
Imazethapyrat 80 g/ha PoE	13.98 (195.2)	35.88	25.80	20.67	0.98	1.80
Imazethapyr + imazamox (RM) at 80 g/ha PoE	11.62 (134.6)	37.80	32.25	26.12	1.07	1.92
Hand weeding	10.27 (105.1)	40.65	36.96	29.60	1.19	1.52
Weedy check	16.11 (259.1)	25.60	20.45	16.53	0.64	1.03
LSD (p=0.05)	0.60	1.72	2.21	3.00	0.17	-

Table 2. Effect of weed management on nutrients uptake in blackgram and physico-chemical properties of soil

Treatment	Nutrients uptake by blackgram (kg/ha)			Physico-chemical properties of soil						
	N	P	K	Bulk density (Mg/m^3)	Soil pH	EC (dS/m)	O.C. (g/kg)	Available Nitrogen kg/ha	Available Phosphorus kg/ha	Available Pottash kg/ha
Imazethapyrat 70 g/ha PE	70.46	5.37	85.23	1.43	8.18	0.29	3.6	180.5	12.2	209.1
Imazethapyrat 80 g/ha PE	73.21	7.21	92.23	1.43	8.18	0.28	3.7	185.7	13.6	211.8
Imazethapyr + imazamox (RM) at 70 g/ha PE	82.15	9.81	101.42	1.41	8.16	0.27	3.8	195.3	15.1	215.0
Metribuzin at 200 g/ha PE	75.34	7.98	95.28	1.42	8.17	0.28	3.7	189.6	14.3	211.8
Pendimethalin at 1000 g/ha PE	78.57	8.75	95.86	1.42	8.17	0.27	3.8	192.1	14.9	213.5
Imazethapyrat 70 g/ha PoE	66.21	5.16	82.98	1.45	8.19	0.29	3.6	180.1	12.8	208.4
Imazethapyrat 80 g/ha PoE	61.35	4.98	80.76	1.45	8.19	0.30	3.5	179.7	12.3	207.4
Imazethapyr + imazamox (RM) at 80 g/ha PoE	71.88	6.12	75.38	1.43	8.18	0.29	3.6	182.4	13.5	210.3
Hand weeding	81.74	9.08	97.96	1.40	8.15	0.26	4.0	196.2	15.4	217.0
Weedy check	53.20	3.12	65.90	1.46	8.20	0.30	3.5	166.0	10.1	206.9
LSD (p=0.05)	2.10	1.92	3.31	NS	NS	NS	NS	5.52	1.90	5.86

PE (1.13 t/ha), metribuzin at 200 g/ha PE (1.13 t/ha). Among different herbicides treatments, imazethapyr + imazamox (RM) 80 g/ha PE was recorded highest benefit-cost ratio (2.29) followed by metribuzin 200 g/ha (2.18) and pendimethalin 1000 g/ha (2.17) respectively. The minimum benefit-cost ratio (1.03) of blackgram was recorded in weedy check plot. The better net returns and B:C ratio might be mainly due to higher grain and straw yields to a greater extent as compared to lesser increase in cost of cultivation with these treatments. This is in agreement with Meena *et al.* (2011).

Effect on nutrients uptake and physico-chemical properties of soil

The maximum uptake of nitrogen (82.1 kg/ha), phosphorus (9.8 kg/ha) and pottash (101.4 kg/ha) were recorded with imazethapyr + imazamox (RM) 80 g/ha PE which was at par with two hand weeding and significantly superior with rest of all treatments (**Table 2**). Minimum uptake of nitrogen (53.2 kg/ha), phosphorus (3.12 kg/ha) and potash (65.9 kg/ha) was recorded under weedy check plot. The results are in agreement with Sharma *et al.* (2016).

The soil properties (bulk density, pH, EC and OC) recorded after harvest of crop (**Table 2**) indicates non-significant influence of herbicides on soil properties.

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Efficacy of post-emergence herbicides for weed control in soybean

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ABSTRACT

A field experiment was conducted at Punjab Agricultural University, Ludhiana to study the efficacy of post-emergence herbicides for weed control in soybean. The herbicides (pendimethalin, imazethapyr, imazethapyr + imazamox and quizalofop-p-ethyl) did not show any significant adverse effects on the number, dry weight and leghaemoglobin content of nodules. Application of pendimethalin 0.45 kg/ha as pre-emergence (PE) + hand weeding (HW) at 40 days after sowing (DAS) recorded significantly higher seed yield than other treatments, however, it was at par with two hand weeding. Among the herbicides, imazethapyr at 75 g/ha applied at 3 weeks after sowing (WAS) recorded significantly higher seed yield than pendimethalin 0.45 kg/ha (PE) and weedy check and was at par with imazethapyr + imazamox 70 g/ha and quizalofop-p-ethyl 50 g/ha applied at 3 WAS. Application of pendimethalin 0.45 kg/ha (PE) + HW at 40 DAS provided the highest net returns (` 49496/ha) followed by two hand weedings. However, application of post-emergence herbicides imazethapyr at 75 g/ha and imazethapyr + imazamox 70 g/ha at 3 WAS were found promising in controlling weeds, providing optimum seed yield and higher B:C ratio. In case of scarcity of labour, post-emergence herbicides can play an important role in controlling weeds effectively.

Soybean [*Glycine max* (L.) Merrill] is an important oilseed crop grown globally. Weeds are one of the most limiting factors in successful soybean production. Due to monsoon rainfall in rainy season, weeds grow luxuriantly and their management is very critical factor for the successful production of soybean. Weeds compete for nutrients, water, light and space with crop during early growth period. Raising of soybean requires a lot of labour due to more weeds and farmers generally are not able to harvest profitable yields. Weeds can cause significant seed yield losses in soybean (Jha *et al.* 2014, Singh *et al.* 2014).

Due to involvement of high cost and scarcity of labour for manual weeding, there is a need of application of pre- and post-emergence herbicides in soybean for effective weed control. Mostly farmers are using pendimethalin as pre-emergence herbicide for controlling weeds in soybean. But the application window of pre-emergence herbicides is narrow. Therefore, there was a dire need to explore the possibility of post-emergence herbicides for effective control of weeds.

A field experiment was conducted during rainy season of 2016 at Punjab Agricultural University, Ludhiana (30° 54' N, 75° 48' E, altitude 247 m). The soil of the experimental site was loamy sand, having pH 7.5, organic carbon 0.36%, available P 24.0 kg/ha and available K 150 kg/ha. A total 496.1 mm (22 rainy days) rainfall was received during the crop growing season. The objective was to study the efficacy of post-emergence herbicides namely pre-mix of imazethapyr + imazamox, imazethapyr and quizalofop-p-ethyl against different weeds and their effect on the growth, nodulation and seed yield of soybean. Seven treatments, *viz.* pendimethalin 0.45 kg/ha as pre-emergence (PE), pendimethalin 0.45 kg/ha (PE) + hand weeding (HW) at 40 days after sowing (DAS), imazethapyr 75 g/ha 3 WAS, imazethapyr + imazamox 70 g/ha at 3 WAS, quizalofop-p-ethyl 50 g/ha at 3 weeks after sowing (WAS), two hand weeding at 20 and 40 DAS and weedy check were evaluated in a randomized complete block design with three replications. Post-emergence herbicides and pendimethalin as pre-emergence (within 24 hours of sowing) were applied with a knapsack sprayer fitted with a flat fan nozzle using 375 litres of water per hectare. In case of two hand weeding, weeds were removed manually at 20 and 40 DAS. In weedy check, weeds were allowed to grow during the whole crop growing season. The preceding crop was wheat. After pre-sowing irrigation, at optimum soil moisture, the field was ploughed twice followed by planking. The crop was sown on 11 June, 2016. The sowing of soybean variety '*SL 958*' was done in rows 45 cm apart using a seed rate of 75 kg/ha. The gross plot size was 6.0 m × 2.25 m. The crop was harvested on 3 November, 2016.

Data on weed species count were recorded randomly from each plot at 40 and 70 DAS by using a quadrate of size 50 × 50 cm and then converted to weed species count per m^2. At harvest, weeds from the whole plot were harvested, dried and data were converted to kg/ha. Data on symbiotic parameter, *viz.* number and dry weight of nodules were assessed at 80 DAS. Five plants per plot were randomly selected for number and dry weight of nodules, and then average was worked out. Leghaemoglobin content in nodules was determined at 80 DAS with the method described by Wilson and Reisenauer (1963). At maturity, data on plant height and pods/plant were recorded from randomly selected five plants from each plot. Biological yield and grain yield were recorded on the basis of whole plot area and converted into kg/ha. From the produce of each plot 100 seeds were taken for recording seed index. Harvest index (HI) was also calculated. Gross returns, net returns as well as benefit:cost (B:C) ratio were worked out using prevailing prices of inputs and output. Data were subjected to analysis of variance (ANOVA) in a randomized complete block design as per the standard procedure.

Effect of herbicides

The major weed flora comprised of *Cyperus rotundus, Arechne racemosa, Commelina benghalensis, Digitaria ciliaris* and *Eleucine aegyptiacum*. Weedy check recorded the highest weed density at 40 and 70 DAS **(Table 1)**. Application of imazethapyr 75 g/ha and pre-mix of imazethapyr + imazamox 70 g/ha at 3 WAS recorded the lower weed density of *Cyperus rotundus* at 40 DAS than other treatments.

Dry weight of weeds was significantly affected by different weed control treatments **(Table 2)**. Weedy check recorded the highest dry weight of weeds at 40, 70 DAS and harvest. Application of imazethapyr + imazamox 70 g/ha at 3 WAS recorded the lowest dry weight of weeds at 40 DAS followed by two hand weeding. However, two hand weeding recorded the lowest dry weight of weeds followed by pendimethalin 0.45 kg/ha PE + hand weeding at 70 DAS and at harvest. Application of imazethapyr (Gare *et al.* 2016) and pre-mix of imazamox + imazethapyr (Pandey *et al.* 2007) as post-emergence herbicides effectively controlled weeds in soybean. Hand weeding recorded the lowest dry weight of weeds due to effective elimination of weeds. Similarly, Pal *et al.* (2013) also reported that two hand weeding (20 and 40 DAS) reduced the density and dry weight of weeds more than the herbicidal treatments. Among post-emergence application of herbicides, quizalofop-p-ethyl 50 g/ha at 3WAS recorded the highest dry weight of weeds as it did not control *Cyperus rotundus* and *Commelina benghalensis* **(Table 1)**.

The number and dry weight of nodules and leghaemoglobin content were not significantly affected by different weed control treatments **(Table 3)**. The applied herbicides, did not show any adverse effects on the number and dry weight of nodules and leghaemoglobin content significantly. However, two

Table 1. Effect of different weed control treatments on weed density

Treatment	Weed density/ m^2							
	40 DAS			70 DAS				
	Cyperus rotundus	*Arechne racemosa*	*Commelina benghalensis*	*Cyperus rotundus*	*Arechne racemosa*	*Commelina benghalensis*	*Digitaria ciliaris*	*Eleucine aegyptiacum*
Pendimethalin 0.45 kg/ha PE	12.4 (155)	1.0 (0)	3.3 (11)	8.5(77)	2.7 (8)	4.7 (24)	6.4 (43)	1.0 (0)
Pendimethalin 0.45 kg/ha PE + HW at 40 DAS	10.5 (115)	1.0 (0)	1.8 (3)	9.1 (83)	2.1 (7)	2.2 (5)	3.3 (11)	1.0 (0)
Imazethapyr 75 g/ha at 3 WAS	5.8 (35)	1.8 (3)	1.8 (3)	8.2 (68)	5.1 (27)	4.2 (17)	6.6 (44)	2.9 (9)
Imazethapyr + imazamox 70 g/ha at 3 WAS	5.8 (35)	1.4 (2)	1.8 (3)	7.9 (65)	3.2 (12)	3.1 (9)	6.0 (36)	3.7 (15)
Quizalofop-p-ethyl 50 g/ha at 3WAS	10.3 (108)	1.4 (2)	2.3 (5)	10.4 (109)	4.9 (28)	4.7 (24)	2.0 (4)	1.0 (0)
Two hand weedings at 20 and 40 DAS	10.3 (107)	1.0 (0)	1.4 (2)	10.1 (104)	3.2 (19)	1.8 (3)	1.8 (3)	1.0 (0)
Weedy check	13.9 (196)	2.7 (7)	3.5 (12)	11.1 (123)	9.5 (91)	5.1 (27)	10.0 (101)	10.1 (104)
LSD (p=0.05)	4.3	0.9	NS	NS	3.8	1.7	3.9	3.2

Values are square root transformed ($\sqrt{x+0.5}$), original value mentioned in parentheses hand weeding recorded the highest number and dry weight of nodules and leghaemoglobin content. Aggarwal *et al.* (2014) also reported that post-emergence application of imazethapyr 75 g/ha had no adverse effect on number, dry weight and leghaemoglobin content of nodules in blackgram.

Plant height, branches/plant, seed index, straw yield and harvest index were not significantly influenced by different treatments of weed control **(Table 4)**. Application of pendimethalin 0.45 kg/ha (PE) + HW at 40 DAS recorded the highest pods/ plant followed by two hand weeding. The weedy check decreased the grain yield by 55.1% as compared to two hand weeding. Reduction in soybean seed yield due to uncontrolled weeds has been reported to be 58.8% (Singh and Jolly 2004). Application of pendimethalin 0.45 kg/ha PE + HW at 40 DAS recorded significantly higher seed yield than other treatments which was, however, at par with two hand weeding treatment**(Table 4)** and it might be due to effective control of weeds **(Table 2)**. Integrated use of pendimethalin 0.45 kg/ha and HW has been found effective in soybean (Singh 2005, Singh 2007). Pre-emergence application of pendimethalin controlled the weeds at early stages followed by one hand weeding gave a less competition to the crop. Pal *et al.* (2013) also reported hand weeding as an effective method of weed control for attaining the maximum yield of soybean. Among the herbicides, imazethapyr 75 g/ha applied at 3 WAS recorded significantly higher seed yield than pre-emergence application of pendimethalin 0.45 kg/ha and weedy check and was at par with imazethapyr + imazamox 70 g/ha and quizalofop-p-ethyl 50 g/ha applied at 3 WAS. Imazethapyr 75 g/ha was found effective in soybean (Ram *et al.* 2013). The application of imazethapyr 75 g/ha, imazethapyr + imazamox 70 g/ha, quizalofop-p-ethyl 50 g/ha at 3 WAS and pendimethalin 0.45 kg/ha as pre-emergence recorded 35.6, 32.7, 29.7 and 11.4% higher seed yield of soybean over weedy check. Ram *et al.* (2013) also reported high net returns and B:C ratio with the application of imazethapyr at 75 g/ha.

Table 2. Effect of different weed control treatments on dry weight of weeds

Treatment	Dry weight of weeds (t/ha)		
	40 DAS	70 DAS	At harvest
Pendimethalin 0.45 kg/ha PE	0.63	1.39	1.46
Pendimethalin 0.45 kg/ha PE + HW at 40 DAS	0.91	0.27	0.29
Imazethapyr 75 g/ha at 3 WAS	0.34	1.33	1.08
Imazethapyr + imazamox 70 g/ha at 3 WAS	0.09	1.56	1.32
Quizalofop-p-ethyl 50 g/ha at 3WAS	1.04	1.90	1.57
Two hand weedings at 20 and 40 DAS	0.31	0.24	0.29
Weedy check	1.09	3.37	3.18
LSD(p=0.05)	0.22	0.78	0.55

Table 3. Effect of different weed control treatments on symbiotic traits in soybean

Treatment	No. of nodules/ plant	Dry weight of nodules/plant (mg)	Leghaemoglobin content (mg/g fresh weight of nodules)
Pendimethalin 0.45 kg/ha PE	27.3	74.5	3.80
Pendimethalin 0.45 kg/ha PE + HW at 40 DAS	27.0	75.7	3.82
Imazethapyr 75 g/ha at 3 WAS	26.3	70.8	3.65
Imazethapyr + imazamox 70 g/ha at 3 WAS	25.7	71.5	3.68
Quizalofop-p-ethyl 50 g/ha at 3WAS	26.0	72.0	3.70
Two hand weedings at 20 and 40 DAS	28.7	78.7	3.85
Weedy check	28.0	73.0	3.70
LSD (p=0.05)	NS	NS	NS

Application of imazethapyr and imazethapyr + imazamox was found better than quizalofop-p-ethyl in terms of seed yield of soybean due to better control of weeds **(Table 2)**. Application of quizalofop-p-ethyl at 50g/ha produced lower seed yield of soybean than imazethapyr 75 g/ha (Singh *et al.* 2013).

Application of pendimethalin 0.45 kg/ha (PE) + HW at 40 DAS provided the highest gross and net

Table 4. Plant characters, yield attributes, seed yield, straw yield and harvest index ofsoybean as influenced by different weed control treatments

Treatment	Plant height (cm)	Branches/plant	Pods/ plant	Seed index (g)	Biological yield (t/ha)	Straw yield (t/ha)	Seed yield (t/ha)	Harvest index (%)
Pendimethalin 0.45 kg/ha PE	93.3	3.1	43.9	10.2	5.93	3.98	1.95	33.1
Pendimethalin 0.45 kg/ha PE + HW at 40 DAS	91.9	3.3	57.6	10.5	8.00	5.24	2.75	34.6
Imazethapyr 75 g/ha at 3WAS	91.0	3.1	48.9	10.3	7.85	5.48	2.37	30.2
Imazethapyr + imazamox 70 g/ha at 3 WAS	91.7	3.4	48.3	10.0	7.56	5.24	2.32	30.7
Quizalofop-p-ethyl 50 g/ha at 3WAS	91.8	3.3	46.6	9.9	7.26	4.99	2.27	31.3
Two hand weedings at 20 and 40 DAS	94.1	31	56.7	10.0	7.85	5.14	2.71	34.5
Weedy check	88.9	3.0	38.2	9.7	5.48	3.73	175	32.5
LSD (p=0.05)	NS	NS	10.0	NS	1.63	NS	0.37	NS

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

Treatment	Cost of cultivation (x103 `/ha)	Gross returns (x103 `/ha)	Net returns (x103 `/ha)	B:C ratio
Pendimethalin 0.45 kg/ha PE	20.56	54.07	33.50	1.63
Pendimethalin 0.45 kg/ha PE + HW at 40 DAS	26.96	76.46	49.50	1.84
Imazethapyr 75 g/ha at 3WAS	20.56	65.78	45.21	2.20
Imazethapyr + imazamox 70 g/ha at 3 WAS	21.41	64.38	42.96	2.00
Quizalofop-p-ethyl 50 g/ha at 3 WAS	21.53	62.89	41.36	1.92
Two hand weedings at 20 and 40 DAS	26.21	75.23	49.01	1.87
Weedy check	19.81	48.52	28.70	1.45
LSD (p=0.05)		10.37	10.37	NS

returns followed by two hand weeding **(Table 5)**. It might be due to higher seed yield of soybean. Sharma *et al.* (2016) also reported highest net returns and B:C ratio in pendimethalin 0.75 kg/ha + HW 30 DAS. All the post-emergence herbicides, pendimethalin 0.45 kg/ha (PE) + HW and two hand weedings gave significantly higher gross and net returns than pendimethalin 0.45 kg/ha PE and weedy check. Application of post-emergence herbicide imazethapyr at 75 g/ha gave the highest B:C ratio followed by imazethapyr + imazamox at 70 g/ha, however, the differences were non-significant.

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Herbicides effect on growth, yield and quality of onion

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ABSTRACT

A field experiment was conducted at Birsa Agricultural University, Kanke, Ranchi, during the year 2016-17 to study the effect of herbicides on growth, yield and quality of onion. The treatments comprised of application of oxyfluorfen (0.25 kg/ha) one week before transplanting, oxyfluorfen (0.25 kg/ha) immediately after transplanting, pendimethalin (1.00 kg/ha) one week before transplanting, pendimethalin (1.00 kg/ha) immediately after transplanting, pretilachlor (0.75 kg/ha) one week before transplanting, pretilachlor (0.75 kg/ha) immediately after transplanting, quizolofop-ethyl (1.00 kg/ha) 20 days after transplanting (DAT), hand weeding (HW) and weedy check. Results revealed that highest plant height (66.67 cm), number of leaves (5.98) and neck thickness (4.76 cm) were recorded in hand weeding at all the growth stages, which was at par with pendimethalin immediately after transplanting and pendimethalin one week before transplanting.The increase due to HW was in the tune of 78.88, 55.73 and 59.20% respectively than weedy check whereas, pendimethalin immediately after transplanting of onion recorded 63.94, 52.56 and 51.84% increase over weedy check. Hand weeding recorded 122% more yield (23.71 t/ha) than weedy check (10.68 t/ha). Juice content and TSS was the highest in hand weeding which was at par with pendimethalin immediately after transplanting, application of pendimethalin one week before transplanting and oxyfluorfen immediately after transplanting.

Onion (*Allium cepa*) is the most important crop belonging to family Alliaceae having more demand in domestic market as well as in export market. India occupies 1.05 million hectare with annual production of 16.8 thousand tonnes. Jharkhand accounts for only 322.73 thousand tonnes from 16.39 thousand hectare. The production is low as compared to Maharashtra which accounts for 5361.96 thousand tonnes from 427.93 thousand hectare. Among the various constraints in onion production, weeds pose serious problem in its cultivation which reduce bulb yield to the extent of 40-80% (Verma and Singh 1997). The conventional method of weed control *i.e.*, hoeing and hand weeding is laborious, expensive and insufficient. Moreover, close spacing of the onion transplants and the shallow root system of seedling make the operation of conventional methods quite ineffective against uprooting of weeds. Under such circumstances application of herbicides offer a suitable method of weed control in onion but little information is available. Keeping these factors in view, the present investigation was carried out to study the effect of herbicides on growth, yield, quality and economics of onion.

The investigation was carried out at Birsa Agricultural University (23°17' north latitude, 85°19' east longitude and at an altitude of 625.00 metres above mean sea level.) during winter season of 2016-17 to study the effect of different herbicides on growth, yield and quality of onion. The crop (variety *Agrifound Dark Red*) was transplanted at 45 days after sowing on 13th October 2016 at 20 X 15 cm spacing with fertilizer 110:40:60 kg N:P:K/ha on a sandy loam soil having medium fertility with a pH of 5.8. Treatments comprised of oxyfluorfen 0.25 kg/ha one week before transplanting, oxyfluorfen 0.25 kg/ha immediately after transplanting, pendimethalin 1.0 kg/ha one week before transplanting, pendimethalin 1.0 kg/ha immediately after transplanting, pretilachlor 0.75 kg/ha one week before transplanting, pretilachlor0.75 kg/ha immediately after transplanting, quizolofop-ethyl 1.0 kg/ha 20 days after transplanting (DAT), hand weeding at 25 DAT and weedy check were laid out in randomized block design with three replications. One hoeing at 45 DAT was carried out in order to loosen soils for setting of onion bulbs in all the treatments. Herbicides were applied using hand sprayer. The weed count and dry weight were subjected to square root transformation ($\sqrt{x+1}$) for statistical analysis. The crop was harvested on 15th February 2017. Economics of the treatments was computed based on the prevalent market prices of the inputs used and bulbs produced.

Effect on weeds

Hand weeding caused significant reduction in total weed density compared with other treatments at 30, 60 and 90 DAT while, it was similar with application of pendimethalin at 1.0 kg/ha immediately after transplanting at 120 DAT. Application of pendimethalin immediately after transplanting recorded 60.37% less total weed density as compared to weedy check at 120 DAT. Hand weeding reduced dry weight of total weeds at 30, 60 and 90 DAT being similar to application of pendimethalin immediately after transplanting while, at 120 DAT application of pendimethalin immediately after transplanting or one week before transplanting of onion were similar in reducing weed dry weight, to the tune of 63.50 and 60.11% less than weedy check, respectively. Consequently, application of pendimethalin immediately after transplanting recorded maximum weed control efficiency *i.e.*, 63.45% at 120 DAT followed by application of pendimethalin one week before transplanting *i.e.*, 60.06% and hand weeding recorded 58.64% (**Table 1**).

Weed index is the indicator of losses in the yield due to presence of the weeds. In respect to hand weeding, minimum yield loss or weed index was recorded by application of pendimethalin immediately after transplanting of onion followed by application of pendimethalin one week before transplanting. Maximum weed index was in weedy check plots due to prominent weed-crop competition. Kolse *et al.* (2010) also reported maximum weed index (57.95%) under weedy check plots.

Effect on onion

Hand weeding at 25 DAT being similar to application of pendimethalin immediately after transplanting recorded higher plant height, more number of leaves per plant and higher plant neck thickness compared to other treatments. The increase was to the tune of 78.88, 55.73 and 59.20%, respectively than weedy check whereas, pendimethalin immediately after transplanting recorded 63.94, 52.56 and 51.84% increase over weedy check (**Table 2**). Mawalia *et al.* (2016) also reported superiority of weed control treatments over weedy check. Bulb neck thickness in onion was minimum with hand weeding (1.13 cm) and was similar to application of pendimethalin immediately after transplanting (1.16 cm) and pendimethalin one week before transplanting (1.24 cm) while maximum was with weedy check (1.41 cm). Bulb neck thickness is an important character, because it indicates bulb storage ability. The onion with thin neck diameters are better than thick diameter.Similar results were observed by Rahman *et al.* (2012) and Sampat *et al.* (2014).

Table 1. Total weed density, weed dry weight, weed control efficiency and weed index as influenced by weed control methods in onion

Treatment	Total weed density (no./m^2)				Total weed dry weight (g/m^2)				Weed control efficiency (%)120 DAT	Weed Index (%)
	30 DAT	60 DAT	90 DAT	120 DAT	30 DAT	60 DAT	90 DAT	120 DAT		
Oxyfluorfen (0.25 kg/ha) one week before transplanting	4.00(16)	3.15(9.7)	4.84(23)	5.58(31)	2.67(7.1)	2.32(5.4)	2.91(8.3)	3.35(11)	52.89	20.39
Oxyfluorfen (0.25 kg/ha) immediately after transplanting	3.96(15)	3.06(9.0)	4.59(21)	5.20(27)	2.66(6.8)	2.28(4.8)	3.07(9.2)	3.33(11)	53.54	19.4
Pendimethalin (1.00 kg/ha) one week before transplanting	3.69(13)	2.88(8.0)	4.44(19)	5.01(25)	2.43(5.9)	2.23(4.6)	2.69(7.1)	3.09(9.3)	60.06	4.78
Pendimethalin (1.00 kg/ha) immediately after transplanting	3.50(12)	2.76(7.3)	4.28(18)	4.77(22)	2.28(5.2)	2.17(4.4)	2.55(6.3)	2.95(8.5)	63.45	0.84
Pretilachlor (0.75 kg/ha) one week before transplanting	5.33(28)	3.4(11)	5.75(33)	6.41(41)	3.15(9.7)	2.70(7.0)	3.55(12)	3.83(14)	38.44	49.37
Pretilachlor (0.75 kg/ha)immediately after transplanting	4.40(19)	3.25(10)	5.01(25)	5.69(32)	2.82(7.8)	2.47(6.0)	3.13(9.6)	3.56(12)	46.85	49.23
Quizolofop-ethyl (1.00 kg/ha) 20 DAT	4.20(17)	3.17(9.7)	4.87(23)	5.54(30)	2.75(7.4)	2.43(5.7)	3.04(9.0)	3.48(12)	49.34	36.57
Hand weeding	3.14(10)	2.43(5.7)	4.04(16)	5.17(26)	2.09(4.5)	1.98(3.6)	2.42(5.6)	3.14(9.6)	58.64	0
Weedy check	6.54(42)	4.25(18)	6.96(48)	7.54(56)	4.23(17)	3.83(14)	4.61(21)	4.87(23)	-	55
LSD (p=0.05)	0.18	0.15	0.11	0.09	0.28	0.28	0.16	0.14		

Table 2. Growth, quality parameters, yield and economics of onion production as influenced by weed control methods in onion

Treatment	Growth parameter				Quality parameter				Economics	
	Plant height (cm)	No. of leaves/ plant	Collar neck thickness (cm)	Bulb neckthickness (cm)	Fresh weight of bulb (g)	Juice content per bulb (ml)	Tss (°brix)	Yield (t/ha)	Net return (x10³ `/ha)	B:C
Oxyfluorfen (0.25 kg/ha) one week before transplanting	51.20	5.07	3.62	1.31	62.89	6.53	12.00	18.85	129.08	2.17
Oxyfluorfen (0.25 kg/ha)immediately after transplanting	52.13	5.16	3.71	1.30	63.67	9.07	12.00	19.09	131.42	2.21
Pendimethalin (1.00 kg/ha) one week before transplanting	59.94	5.56	4.27	1.24	72.03	9.20	12.07	22.56	165.92	2.77
Pendimethalin (1.00 kg/ha) immediately after transplanting	61.10	5.87	4.54	1.16	73.44	9.60	12.53	23.48	175.14	2.93
Pretilachlor (0.75 kg/ha) one week before transplanting	43.70	4.67	3.01	1.40	44.44	3.80	11.33	11.99	60.38	1.01
Pretilachlor (0.75 kg/ha)immediately after transplanting	45.98	4.51	3.05	1.40	44.03	4.80	11.47	12.03	60.81	1.02
Quizolofop-ethyl (1.00 kg/ha) 20 DAT	49.07	4.96	3.57	1.31	53.69	6.13	11.60	15.03	90.88	1.52
Hand weeding	66.67	5.98	4.76	1.13	74.06	9.73	13.20	23.71	130.24	1.22
Weedy check	37.27	3.84	2.99	1.41	39.51	3.60	11.00	10.68	51.00	0.91
LSD (p=0.05)	11.13	0.45	0.83	0.14	10.10	1.52	1.24	1.14		

Effect on yield

Maximum bulb yield was recorded in hand weeding plots followed by pendimethalin immediately after transplanting of onion which were at par with each other. Hand weeding recorded 122% more yield than weedy check. More yields in hand weeding plots (23.71 tha) seemed to be due to better weed control efficiency which might have created favourable environment by the clean crop culture resulting in more utilization of resources, more photosynthetic rates and higher yield. Among the herbicidal treatments, maximum yield was recorded with pendimethalin immediately after transplanting (23.48 t/ha) followed by application of pendimethalin one week before transplanting (22.56 t/ha) and oxyfluorfen immediately after transplanting (19.09 t/ ha) due to their ability to inhibit emerging weeds. Similar results were observed by Tripathy *et al.* (2013) and Vashi *et al.* (2012).

Effect on quality

Hand weeding at 25 DAT being similar to application of oxyfluorfen immediately after transplanting, pendimethalin one week before transplanting and pendimethalin immediately after transplanting of onion recorded maximum juice content (9.73 ml) and total soluble solids (TSS) (13.20 °Brix), which was 170.27 and 20% more than the weedy check, respectively.

Economics

Application of pendimethalin immediately after transplanting of onion recorded higher net returns (70.88%) and B: C ratio (68.94%), followed by application of pendimethalin one week before transplanting, oxyfluorfen immediately after transplanting and oxyfluorfen one week before transplanting.

It was concluded that application of herbicide is as good as hand weeding in controlling weeds as well as in achieving yield in onion. Application of pendimethalin immediately after transplanting of onion may be recommended for achieving the highest productivity and profitability in onion.

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Leaching potential of oxyfluorfen in soil

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ABSTRACT

Leaching potential of oxyfluorfen herbicide was evaluated in clay loam soil under laboratory conditions with simulated rainfall. Oxyfluorfen was applied at 240 and 480 g/ha on 60 cm long soil columns. Oxyfluorfen leached upto 10 cm soil depth but, maximum concentration (84.5%) of the total herbicide applied was observed on upper top soil. Residues were not detected in leachates. Study indicates low mobility of oxyfluorfen in clay loam soils under saturated moisture conditions and may not pose ground water contamination problem if not used indiscriminately.

Leaching and runoff are the major transportation processes responsible for water contamination (Singh *et al.* 2017). The presence of pesticide residues in water is a major concern worldwide, as water is a source of drinking and irrigation in most of the countries (Tandon 2017). Oxyfluorfen [4-[2-chloro-4-(trifluoromethyl)phenoxy]-2-ethoxy-1-nitrobenzene] is a diphenyl ether herbicide with selective pre-emergence and post-emergence activity, used primarily to control broadleaf weeds and some grasses and used in various agricultural, plantation, medicinal and horticultural crops. Oxyfluorfen has potential to affect aquatic ecological systems and is toxic to aquatic plants, invertebrates and fishes. Oxyfluorfen is classified as a possible human carcinogen (EPA 2002).

Leaching of pesticides is considered as one of the main cause for ground water contamination (Tandon *et al.* 2016, Tandon 2018). Literatures on oxyfluorfen under Indian conditions are fewer (Janki *et al.* 2013, Sondhia 2008). Therefore pesticide-leaching studies, are necessary to determine their potential to contaminate ground water. Keeping in view of above facts leaching behaviour of oxyfluorfen was studied under simulated rainfall in laboratory conditions to estimate the extent of leaching of the herbicide in soil and predicting the extent of pollution it can cause to ground water.

Soil samples of different depth, *i.e.* 0-15 cm, 15-30 cm, 30-45 cm, and 45-60 cm from the N.E.B. Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India was collected, air dried and passed through a 2mm sieve and analysed for its physio-chemical properties.

Chemicals used during the course of this study were all of Analytical and HPLC grade. Triple distilled water was prepared in laboratory by using quartz distillation unit. All the glasswares used in the present study were of Borosil and Corning make. The technical grade oxyfluorfen (95.0% pure) was obtained by courtesy of M/S Willowood Chemicals, Hongkong and commercial grade of oxyfluorfen (Goal 24 EC) was obtained by courtesy of M/S Dow Agro sciences, India for leaching experiments.

Leaching experiment was conducted in department of Chemistry (Division of Agricultural Chemicals), G. B. Pant University of Agriculture and Technology, Pantnagar at room temperature (28±2°C) and arranged in completely randomized design with three replications. The leaching studies were performed in PVC (polyvinyl chloride) columns (10 cm internal diameter and 60 cm long). The column were cut longitudinally into two halves and rejoined by using packing tape. The average volume of the tubes was recorded. The one end of PVC column was covered with muslin cloth and a funnel was attached to the bottom of each column for collection of leachates into 1000 ml flasks. Individual columns were packed with 6500 g clay loam soil. Columns were filled with soil according to the different depth taken. Columns were saturated overnight by flowing water from above and also keeping them dipped in water contained in a bucket. Excess water was drained out by 1 day drainage cycle and columns were covered with aluminum foil to prevent evaporation. For monitoring vertical movement and leaching loss of oxyfluorfen, 10 ml of oxyfluorfen formulation was applied to surface of column with pipette at recommended dose (240 g/ ha) and double recommended (480 g/ha).

The addition of water was done for ten days at the rate of 45 ml for 12 hrs per day so that infiltration rate of soil would not be exceeded. A set of soil columns receiving same amount of water only served as control. Water eluting from the column was collected daily in flask and processed for analysis for herbicide. After ten days, when addition of water was completed, the soil columns were allowed to dry for 24 hours. Columns were cut into two halves and the soil was cut into 5 cm segment each and processed for residue analysis.

A 20 g representative air dried soil sample was extracted with 50 ml of dichloromethane: methanol (1:3 v/v) shaked over a orbital shaker for one hour and filtered. The procedure was repeated twice with 25 ml of solvent mixture. All filtrate were pooled and concentrated to 1 ml under vacuum at 45±1°C. The extract was loaded on a pre-washed solid phase C-18 solid phase extraction (SPE) cartridge and eluted by using methanol. Elute obtained was dried under vacuum and the residue was filtered through 0.22µm Millipore PTFE filter and dissolved into HPLC grade acetonitrile for further analysis.

Leachate samples (25 ml) were filtered and liquid –liquid partioned with methylene chloride (50 ml x 3), organic layer was collected, pooled and was dried over anhydrous sodium sulphate and volume was reduced to dryness in a rotary vacuum evaporator (40±1°C). The residue was dissolved in 5 ml mobile phase and iltered through 0.22µm Millipore PTFE filter.

The Beckman model 322 Gradient HPLC system with fixed UV wavelength detector was used for detection. The operating parameters were Supelco's ODS-II column 2.5µm (250mm X 4.6mm), mobile phase Acetonitrile: Methanol: Water: (6:3:1v/v) with isocratic mode at a flow rate of 1ml/min, chart speed 1 cm/min, aufs 0.02 and UV detection at 229nm. The retention time was 4.1 min.

Recovery studies were carried out by fortifying the untreated sample of soil and water at 0.5 and 1.0 mg/ kg with oxyfluorfen and processed by following the methodology as described above. Average recoveries for oxyfluorfen in soil and water were 87.5-90.0% and 93.4-95.6%, respectively. The compound in the samples was identified and quantified by comparison of the retention time and peak heights of the sample chromatograms with those of standard runs under identical operating conditions. Limit of detection was (LOD) was 0.003 mg/kg and limit of quantification (LOQ) was 0.01 mg/kg.

Soil used was clay loam (clay 36%: silt 40%: sand 24%) with 1.32% organic carbon, pH 7.54, $CaCO_3$ 0.482 and EC 0.177 ms. The amount of residues of oxyfluorfen in different fractions of leachates which were collected from 1 to 10 days showed that, no residues of oxyfluorfen was detected in the fractions of leachates from day 1st to 10th day at recommended and double rate of application. The distribution of herbicide residues in soil cores at different depths after passing 450 milliliters of water are presented in **Figure 1**.

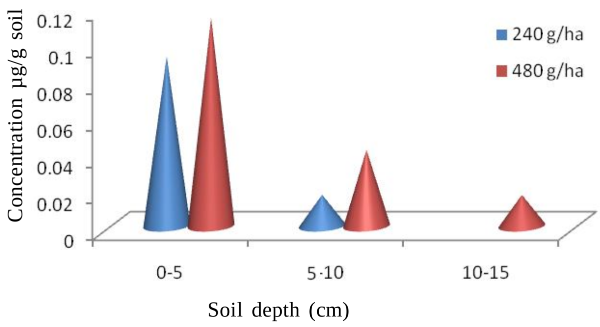

Figure 1. Leaching of oxyfluorfen at 240 g/ha and 480 g/ ha in soil

Data revealed that the surface applied oxyfluorfen got distributed only in the upper part of the column. At both application rates the residue concentration was maximum in the upper soil layers of column, mainly at the depth from 0 to 5 cm, it start decreasing from 5 to 10 cm and beyond this soil depth. Oxyfluorfen did not moved beyond 15 cm soil column indicating low mobility of oxyfluorfen in soil column. At 240 g/ha dose total herbicide retained was 89.0% while, in case of 480 g/ha dose the retention was 89.9% in soil. At 240 g/ha rate about 84.5% of the herbicide remained in 0-5 cm soil depth while, 15.5% leached to the 5-10 cm depth, whereas, in case of 480 g/ha 66.02% remained at 0-5 cm depth and 30.0% leached to lower depths.

The results are contrary with the findings of Sondhia (2008), where high movement of oxyfluorfen in clay soil was reported and residues of oxyfluorfen reached beyond 85 cm soil depth under natural rainfall condition (830 mm rainfall), and herbicide residues were also detected in leachates. According to Wauchope *et al.* (1992) oxyfluorfen is very well adsorbed to soils and herbicide-soil binding were highest in soils with high organic matter and clay content and oxyfluorfen would not leach below 4 inches in soils except sandy soils. Once oxyfluorfen is adsorbed to soil particles, it is not readily removed. Oxyfluorfen is practically insoluble in water, and therefore is unlikely to be appreciably mobile in most instances, unless the sorptive capacity of the soil is exceeded (WSSA 1994).

Oxyfluorfen has high affinity to organic carbon and therefore less susceptible to leaching. In our condition the soil was rich in organic matter with high percentage of clay and silt, this might be the reason for slow movement of oxyfluorfen under saturated moisture conditions in mollisol soil. Yen *et al*. (2003) also reported similar findings of low movement of oxyfluorfen in soil. In very low organic carbon content and coarse texture soils, oxyfluorfen has potential to contaminate ground water less than 3 m deep (Ying and Williams 2000)

Results revealed that oxyfluorfen was not mobile in clay loam soil column, it did not leached beyond 15 cm depth (at double dose) that would cause significant ground water pollution. Results of the controlled laboratory studies cannot be reliably extrapolated to field conditions and field studies will be a more realistic approach for finding the real leaching potential.

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First observation of field dodder and its host range in Meghalaya

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Cuscuta campestris, Convolvulaceae, Extended distribution, Parasitic weed

ABSTRACT

The present paper reports the first observation of a field dodder, *Cuscuta campestris* Yuncker from Meghalaya, Northeast India. Detailed field study has revealed a total of 51 host plant species, with *Mikania micrantha* Kunth., *Parthenium hysterophorus* L. and *Duranta erecta* L. being most favorable hosts. Anatomical study revealed that the parasite deteriorates the host plant by infiltrating its haustoria deep into the vascular bundles. It may also act as an economic threat to agricultural and horticultural sector in the state, as it largely reduces the host vigour and crop production. Therefore, there is an urgent need to control its invasion in the state.

Field dodder (*Cuscuta campestris*) is an annual obligate stem holoparasitic species belonging to the family Convolvulaceae (Cuscutaceae). The genus *Cuscuta* comprises of about 200 parasitic plant species, distributed throughout the tropical, subtropical and temperate regions of the world with Americas as centres of diversity (Yuncker 1932). In India, about 12 species have been documented, of which only one species (*C. reflexa*) has been reported from northeast India (Haridasan and Rao 1987). The species of the genus are without chlorophyll, have neither roots nor fully expanded leaves and the stem is only vegetative part. It twins around the leaf or stem of a suitable host plant and penetrates the host stems in order to obtain nourishment, hence weakening the host.

Globally, about 20 species of *Cuscuta* are identified as devastating weeds in agricultural and horticultural farms (Dawson *et al.* 1994). Out of 12 species reported from India, *C. campestris* and *C. reflexa* are more common (Mishra 2009). Genus *Cuscuta* has a long been used in traditional herbalism in India (Chopra *et al.* 1992). The extract of stem is used for the treatment of rheumatism, antidote for poisoning, leucorrhoea, respiratory, urinary, spleen, eye complaints, fever *etc*. (Chopra *et al*. 1992), antidandruff, anti-lice, body aches, joint pains and is believed to have anti-fertility effect (Kala *et al.* 2004).

C. campestris binds itself to a variety of host plants including agricultural crops and causes severe damage to them (Mishra *et al*. 2007). Damage can finally express to total destruction and death of the host. It reproduces mainly by seeds, which germinate under relatively high temperature and is dispersed by the wind, water, birds and animals. The seeds remain viable in the soil for about 10-30 years and may germinate throughout the year (Wisler and Norris 2005). Besides it behaves as a vector for numerous plant pathogens, such as *Cucumber Mosaic* Virus and *African Cassava Mosaic* Virus (Wisler and Norris 2005).

During a recent floristic exploration, a few specimens belonging to the genus *Cuscuta* were collected from upper parts of Umiam Lake in Meghalaya. Based on critical examination the specimens were identified as *Cuscuta campestris*. A thorough scrutiny of literature (Haridasan and Rao 1987) and records of herbarium specimens housed at Botanical Survey of India, Eastern Regional Centre, Shillong (ASSAM) and North Eastern Hill University, Shillong revealed that the species is a new record to Northeast India. The pressing and mounting of the specimen were done using standard procedures and latter deposited at Herbarium of Department of Botany, North-Eastern Hill University, Shillong, Meghalaya. The anatomical details were studied for two host plant species (*Mikania micrantha* and *Eleusine coracana*). The infected plant parts were fixed in FAA (formalin, acetic acid and ethyl alcohol, 10:5:85 v/v), followed by dehydration in the 85%, 95%, 100% ethanol and xylene, and then embedded in paraffin. The transverse section of petiole and stem of the species were taken with a rotary microtome, stained with toluidine blue O, mounted in DPX (dibutyl phthalate xylene) and observed under Labomed Cxl Microscope.

Taxonomic enumeration

Cuscuta campestris Yuncker, Mem. Torrey Bot. Club. 18: 138. 1932 **(Figure 1)**.

An annual leafless twining obligate stem parasite. Stem thin, filiform, slender, yellow or pale yellow, glabrous, ca. 0.8 mm in diam., densely branched. Leaves absent or reduced to minute scales. Inflorescence lateral, compact, branched, tightly clustered, umbelliform, 5-10 flowered, subsessile to peduncled; peduncle 2-3 mm long. Flowers hermaphrodite, white, ca. 4 mm long; bracts scale–like, light brown, ca, 0.6 mm long or sometimes obsolete; Pedicals ca. 1 mm. Calyx copular; lobes 5, obtuse-orbicular, 2-2.5 mm long, fleshy, slightly greenish in colour, glandular, glossy, covering more than half of corolla, ridged on outer surface, apex obtuse. Corolla campanulate, 3-3.5 mm long, white, flashy; lobes 5, inflexed, spreading, 0.8-1.4 x 0.5-1 mm, glossy, with reticulate venation, apex acute, fringed; tube ca. 1.5 mm long, corolla scales oblong, fimbriate above, reaching to stamens, persistent. Stamens 5, inserted at corolla throat, filament broader at the base and tapering towards the apex, subulate, longer than the anther, white, 0.4-0.6 mm long; anther oblong-elliptical to oval, ca. 0.3 mm long, yellow, exserted. Ovary sub globose, fleshy, ca. 1.5 mm long; locus 2, ovules 3-4; styles 2, filiform, thin, divergent, 1.5-2 mm long; stigma capitates or rounded ca. 0.2 mm long. Capsule depressed-globose, ca. 3 mm across, membranous, irregularly dehiscent, enclosed by persistent sepal lobes, petals and stamens. Seeds 2-4 in each capsule, broadly ovate, flattened on one side, 1-2 mm long, pale brown, scabrous. Flowering and fruiting: throughout the year.

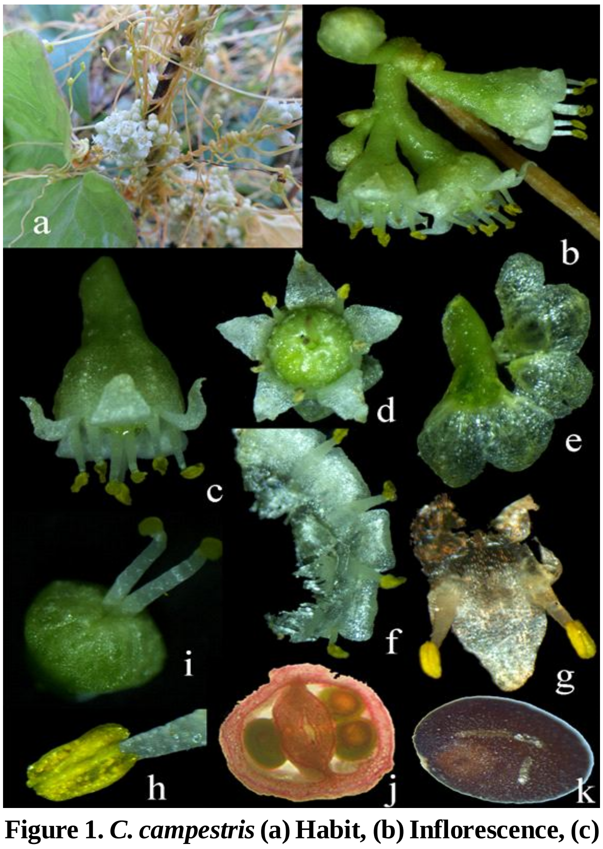

Figure 1. ***C. campestris*** **(a) Habit, (b) Inflorescence, (c) & (d) Individual flower in full bloom, (e) Sepals, (f) Dissected petals with fimbriation, (g) Single petal lobe with attached stamens, (h) Stamen, (i) Gynoecium, (j) T.S. of ovary and (k) Seed**

Specimen examined: India, Meghalaya, East Khasi Hill District, 25^0 40.151' N and 91^0 45.291' E, 1015 m asl, road side Umiam lake area, 12054, 08 May 2016, N. A. Bhat, Department of Botany, North-Eastern Hill University, Shillong (NEHU).

Distribution: Asia (China, India, Afghanistan, Indonesia, Japan, Kazakhstan, Korea, Mongolia, Sri Lanka) Russia, Africa, Australia.

Host range

During the current study, a total of 51 plant species, including 30 herbs, 15 shrubs, 4 climbers and 2 trees were found to be hosted by *C. campestris* (**Table 1**). Mostly herbs were found to be affected by the parasite, while the trees are resistant. *M. micrantha* Kunth, *Parthenium hysterophorus* L. and *Duranta erecta* L. were observed as the most preferred host plants. *Vitex negundo* and *Duranta plumier* has also been reported as favourable host plants for the

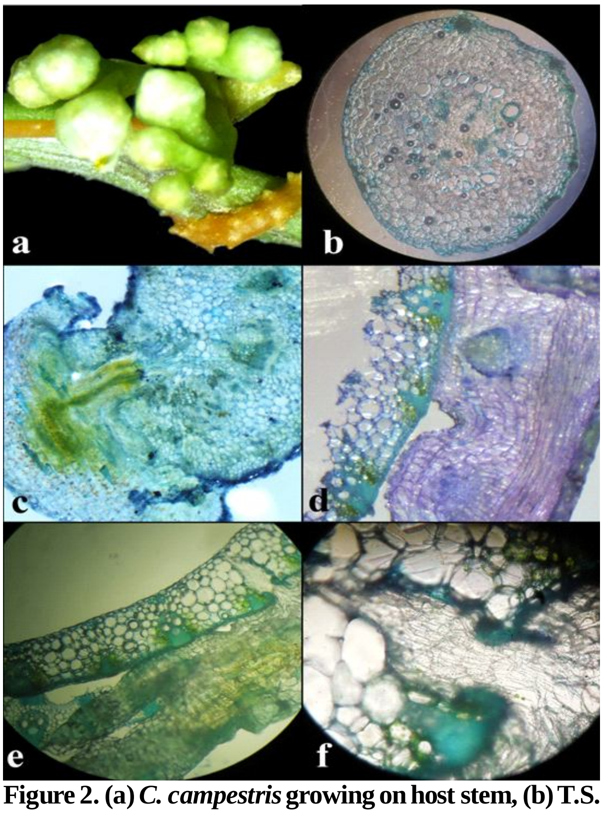

Figure 2. (a) ***C. campestris*** **growing on host stem, (b) T.S. of parasite stem showing haustorial initials (HI), (c) Parasite binding with** ***Mikania micrantha*****, (d, e and f) Development and penetration of haustoria into the vascular bundle of** ***Eleusine coracana***

Table 1. List of host plants infected by *C. campestris* in Meghalaya

Host species	Family	Habit	Part infected
Sambucus javanica Blume	Adoxaceae	S	L
Achyranthes aspera L.	Amaranthaceae	H	L/ST
Alternanthera sessilis (L.) R.Br. ex DC.	Amaranthaceae	H	L/F
Chenopodium album L.	Amaranthaceae	H	L/ST/I
Iresine herbstii Hook.	Amaranthaceae	H	L/ST
Catharanthus roseus (L.) G.Don	Apocynaceae	S	L/ST
Tabernaemontana divaricate (L.) R.Br.	Apocynaceae	S	L/F
Xanthium strumarium L.	Asteraceae	S	L/ST/I
Bidens pilosa L.	Asteraceae	H	L/ST
Parthenium hysterophorus L.	Asteraceae	H	L/ST
Mikania micrantha Kunth	Asteraceae	C	L/ST/I
Ageratina adenophora (Spreng) R.M. King & H.Rob.	Asteraceae	H	L/ST/I
Erigeron bonariensis L.	Asteraceae	H	L/ST
Artemisia nilagirica (C.B. Clarke) Pamp.	Asteraceae	H	L/ST/I
Crassocephalum crepidioides (Benth.) S.Moore	Asteraceae	H	L/ST/I
Ipomoea indica (Burm.) Merr.	Convolvulaceae	C	L/ST
Cyperus iria L.	Cyperaceae	H	L
Ricinus communis L.	Euphorbiaceae	S	L/ST
Euphorbia hirta L.	Euphorbiaceae	H	L/ST
Trifolium repens L.	Fabaceae	H	L/ST
Flemingia strobilifera (L.) W.T. Aiton	Fabaceae	S	L/I
Callicarpa arborea Roxb.	Lamiaceae	T	L
Vitex negundo L.	Lamiaceae	S	L/ST/I
Clerodendrum infortunatum L.	Lamiaceae	S	L/ST
Sida acuta Burm.f.	Malvaceae	H	L/ST
Hibiscus rosa-sinensis L.	Malvaceae	S	L/ST
Hibiscus surattensis L.	Malvaceae	C	L/ST
Urena lobata L.	Malvaceae	S	L/ST
Oxalis corniculata L.	Oxalidaceae	H	L/ST/F
Phyllanthus urinaria L.	Phyllanthaceae	H	L/ST/F
Phytolacca acinosa Roxb	Phytolaccaceae	H	L/ST
Plantago asiatica L.	Plantaginaceae	H	L
Paspalum conjugatum P.J. Bergius	Poaceae	H	L
Oryza sativa L.	Poaceae	H	L
Eleusine coracana (L.) Gaertn.	Poaceae	H	L
Paspalum scrobiculatum L.	Poaceae	H	L
Imperata cylindrica (L.) Raeusch.	Poaceae	H	L
Poa annua L.	Poaceae	H	L
Fagopyrum esculentum Moench	Polygonaceae	H	L/ST/I
Persicaria barbata (L.) H. Hara	Polygonaceae	H	L/ST
Rubus ellipticus Sm.	Rosaceae	S	L
Citrus medica L.	Rutaceae	T	L
Solanum americanum Mill.	Solanaceae	H	L/ST
Brugmansia suaveolens (Humb . & Bonpl. ex Willd.) Bercht. & J.Presl	Solanaceae	S	L/ST/F
Solanum aculeatissimum Jacq.	Solanaceae	H	L/ST/F
Solanum torvum Sw.	Solanaceae	S	L/ST
Nicandra physalodes (L.) Gaertn.	Solanaceae	H	L/ST/F
Boehmeria macrophylla Hornem.	Urticaceae	H	L/ST
Duranta erecta L.	Verbenaceae	S	L/ST
Lantana camara L.	Verbenaceae	S	L/ST
Sechium edule (Jacq.) Sw.	Cucurbitaceae	C	L/ST

Legend: H= Herb, S= Shrub, T= Tree, C= Climber, L= Leaves, ST= Stem, F= Flower, I= Inflorescence

species (Nikam *et al.* 2014). Monocot species are considered to be resistant to *Cuscuta* invasion, probably because of barriers formed by anatomical positions such as the arrangement of vascular bundles or incompatibility of signals that are important for forming interspecies connections of vascular strands or by direct defense response applied by the host (Dawson *et al.* 1994). But in our study, we observed that monocotyledons (*P. conjugatum*, *E. coracana* and *I. cylindrical*) were also affected by the parasite.

The starting point of infection in the host is the appearance of adhesive elongated disk like structure. The anatomical sections of a monocot (*E. coracana*) and dicot (*M. micrantha*) host stem showed a notable variation (**Figure 2**). In the case of *M. micrantha*, haustorium penetrates into the stem, while in *E. coracana*, it affects only the leaves. The prevention of haustoria penetration to monocot stem could be because of lignified tissues and absence of epidermal hairs or sclerenchymatous hypodermis in monocots (Dawson *et al.* 1994). The attachment zone showed that the epidermal and cortical cells are destroyed by the penetration of the haustoria of the weed, which latter establishes the link between xylem vessels and sieve-tubes. Haustoria originate from the cortical parenchyma cells of the pericycle, undergo a high rate of proliferation and reach the vascular tissues of the host by rupturing the bulliform cells in order to obtain nourishment.

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Effect of fertilizer and weed management practices on growth and yield of *bidi* tobacco

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ABSTRACT

An experiment was conducted on loamy sand soil at *Bidi* Tobacco Research Station Farm, Anand Agricultural University, Anand, Gujarat during 2011-12 and 2012-13. Twenty treatment combinations comprising of four levels of fertilizer management (control; ammonium sulphate: 200 kg/ha; castor cake: 200 kg/ha and neem cake: 200 kg/ha) and five weed management treatments (unweeded, manual weeding, pendimethalin 1.0 kg/ha, isoproturon 1.0 kg/ha and glyphosate 1.0 kg/ha) were tried out in a factorial RBD with four replications. The application of ammonium sulphate at 200 kg/ha along with irrigation and manual weeding of broomrape were found to be the best practices.

Tobacco (*Nicotiana tabacum* L.) is the most important non-food crop cultivated in more than 100 countries on approximately 4.2 million hectares of land (Anonymous. 2010). The major tobacco growing countries in the world are China, USA, India, Brazil, Turkey, Russia, Italy and Zimbabwe. Tobacco (*Nicotiana tabacum* L. and *Nicotiana rustica* L.) belongs to the order tubiflorae and family solanaceae and is believed to have been introduced in India from its native Central America by Portuguese in 1603.

In India, tobacco cultivation is grown mainly in Andhra Pradesh, Gujarat, Karnataka, Uttar Pradesh, Bihar, West Bengal, Maharashtra and Tamil Nadu. Chewing Tobacco is grown in Tamil Nadu, Gujarat, Bihar, West Bengal and Uttar Pradesh. Gujarat is the largest *Bidi* tobacco growing state in the country. (Anonymous 2006). In Gujarat, it is grown in Anand, Kheda, Vadodara and Panchmahal districts covering an area of around 90,000 ha. (Patel and Laxminarayan, 2006). The area, production and productivity of *bidi* tobacco cultivated in Kheda district during the year 2011-12 was 26400 (ha), 390 (‘00’ MT) and 14.75 (q/ha), respectively. (Anonymous 2012).

Bidi tobacco industry is essentially a cottage industry employing more than 30 lakh of rural population in India. *Bidi* tobacco plays a vital role in the national economy in generating employment and revenue. Gujarat is the largest *Bidi* tobacco growing state in the country. (Anonymous 2006). Among different types of tobacco grown in the country, *Bidi* tobacco (*Nicotiana tabacum* L.) accounts for the highest area (32% of total) and production (36% of total) in the country.

Considering the importance of different management practices on growth and yield of *bidi* tobacco, the present experiment was conducted with an objective to study the effect of different fertilizer and weed management practices on growth and yield of *bidi* tobacco (*Nicotiana tabacum* L.) under middle Gujarat conditions.

A field experiment was conducted during the June to March of the years 2011-12 and 2012-13 at *Bidi* Tobacco Research Station, Anand Agricultural University, Anand, Gujarat. The texture of the soil is loamy sand. The soil is very deep and fairly moisture retentive. The soil was low in organic carbon and nitrogen, high in available phosphorus and medium in potassium with pH 7.6. The soil was free from any kind of salinity/sodicity hazards. Twenty treatment combinations comprising of four fertilizer management treatments, *viz*. control; ammonium sulphate: 200 kg/ha; castor cake: 200 kg/ha and neem cake: 200 kg/ha and five herbicide management treatments, *viz*. unweeded, manual weeding, pendimethalin 1.0 kg/ha, isoproturon 1.0 kg/ha and glyphosate 1.0 kg/ha were evaluated in a factorial RBD with four replications.

Effect of different fertilizer management treatments

The plant height and leaf length measured at harvest due to different fertilizer management treatments were found non-significant during the year 2011-12, 2012-13 and on pooled analysis.

Different fertilizer management did not significantly influenced leaf width measured at harvest during both the years. However pooled analysis, ammonium sulphate 200 kg/ha recorded significantly higher leaf width (27.27 cm) which was statistically at par with treatment neem cake 200 kg/ha and castor cake 200 kg/ha. The nitrogen applied through ammonium sulphate might be responsible for vegetative growth of tobacco crop. Significantly lower leaf width (25.66 cm) was found in control. This could be attributed to severe crop weed competition wherein weeds had utilized in control. Results are in conformity with those of Abu-Irmaileh (1981), Westwood and Foy (1999) and Mariam and Suwanketnikom (2004).

With regard to cured leaf yield, ammonium sulphate 200 kg/ha has recorded significantly higher cured leaf yield (2.2 t/ha) and control has recorded lower cured leaf yield (1.98 t/ha) in pooled analysis. However both these treatments remained statistically at par with castor cake 200 kg/ha and neem cake 200 kg/ha. Treatment ammonium sulphate, 200 kg/ha indicated 12.2% higher cured leaf yield as compared to the treatment control (**Table 1**). It might be due to all broomrape species were much more sensitive to ammonium toxicity than host crop species under similar treatment conditions. Hence, broomrape infestation in *bidi* tobacco was drastically reduced and cured leaf yield was increased when $(NH_4)_2SO_4$ was applied. The results are in accordance with the results reported by Abu-Irmaileh (1981), Westwood and Foy (1999) and Mariam and Suwanketnikom (2004).

In case of stalk yield, the differences were found non-significant due to different levels of management through fertilizers.

Effect of different weed management treatments

Different herbicide treatments were found equally effective on plant height. Among different weed management treatments, manual weeding recorded significantly the highest leaf length (50.16, 42.98 and 46.57 cm), respectively during the years 2011-12, 2012-13 and on pooled basis. The minimum values of weed density and weed biomass as well as dry weight of broomrape at harvest in manual weeding could be the reason for higher leaf length. These results are in agreement with the findings of Krishnamurthy and Rao (1976) and Ramchandra Prasad (2011).

Significantly the highest leaf width was observed with manual weeding during both the years (2011-12, 2012-13) and on pooled basis (29.51, 28.33 and 28.92 cm) respectively.

With respect to average cured leaf yield, manual weeding recorded significantly higher cured leaf yield (2.23 t/ha) which was statistically at par with pendimethalin 1.0 kg/ha, isoproturon 1.0 kg/ha and glyphosate 1.0 kg/ha treatments. On the contrary, unweeded control gave significantly lower cured leaf yield (1.94 t/ha) on pooled data. Manual weeding recorded 15.1% higher cured leaf yield as compared to unweeded control. Higher dry matter production of tobacco leaves with manual weeding of broomrape

Table 1. Growth and yield attributes at harvest of *bidi* tobacco as influenced by fertilizers and weed management

Treatment	Plant height (cm)			Leaf length (cm)			Leaf width (cm)		
	2011-12	2012-13	Pooled	2011-12	2012-13	Pooled	2011-12	2012-13	Pooled
Fertilizer management									
Ammonium sulphate; 200 kg/ha at emergence of *Orobache* with irrigation	90.05	88.53	89.29	47.25	37.16	42.21	27.53	27.02	27.27
Castor cake; 200 kg/ha at 3rd week after transplanting	89.34	89.25	89.29	45.98	38.60	42.29	26.27	26.41	26.34
Neem cake; 200 kg/ha at 3rd week after transplanting	88.04	87.32	87.68	47.48	40.53	44.00	26.81	27.06	26.94
Control	85.50	84.16	84.83	44.88	37.08	40.98	25.72	25.61	25.66
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	1.06
Weed management									
Pendimethalin at 1.0 kg/ha at emergence of *Orobache* with irrigation	88.28	88.06	88.17	46.59	38.25	42.42	26.68	26.61	26.64
Isoproturon at 1.0 kg/ha at emergence of *Orobache* with irrigation	88.78	89.31	89.04	46.00	37.75	41.88	26.35	27.16	26.75
Glyphosate at 1.0 kg/ha at emergence of *Orobache* with irrigation	87.54	86.50	87.02	45.01	37.11	41.06	25.81	26.66	26.23
Manual weeding as and when required	87.61	84.49	86.05	50.16	42.98	46.57	29.51	28.33	28.92
Unweeded	88.94	88.21	88.57	44.23	35.63	39.93	24.56	23.85	24.21
LSD (p=0.05)	NS	NS	NS	3.68	3.33	2.45	1.69	1.71	1.19
Interaction *Fertilizer management × Weed management*	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V. %	9.63	9.13	4.69	11.19	12.27	5.85	9.00	9.11	4.53

Table 2. Yield and economics as influenced by different fertilizer and weed management treatments (average of two years)

Treatment	Yield (t/ha)		Gross return (x10^3 `/ha)	Total cost of cultivation (x10^3 `/ha)	Net return (x10^3 `/ha)	BCR
	Cured leaf	Stalk				
Fertilizer management						
Ammonium Sulphate; 200 kg/ha	2.22	1.77	66.14	33.56	32.59	1.97
Castor cake; 200 kg/ha	2.04	1.66	60.86	33.51	27.35	1.82
Neem cake; 200 kg/ha	2.07	1.72	61.71	35.19	26.51	1.75
Control	1.98	1.60	59.00	31.42	27.59	1.88
Weed management						
Manual weeding	2.23	1.72	66.63	35.37	31.26	1.88
Pendimethalin at 1.0 kg/ha	2.06	1.70	61.23	33.76	27.46	1.81
Isoproturon at 1.0 kg/ha	2.09	1.67	62.23	33.15	29.08	1.87
Glyphosate at 1.0 kg/ha	2.06	1.69	61.53	33.08	28.45	1.86
Unweeded	1.94	1.63	57.97	31.72	26.25	1.83

Sale price: (1) Year: 2011-12: Cured leaf: ` 24.15/kg; Stalk: ` 00.50/kg; (2) Year: 2012-13: Cured leaf: ` 35.25/kg; Stalk: ` 00.50/kg

and herbicide treatments was due to either low broomrape infestation or short broomrape competition period. The results are substantiated with the studies conducted by Dhanapal *et al.* (1998), Giridhar and Mahadevaswamy (2003), Kataria *et al.* (2003), Nadal *et al.* (2008), Anonymous (2009-10), Ramchandra Prasad (2011).

Interaction effect

The interaction effect was found non-significant in plant height, leaf length, leaf width, cured leaf yield and stalk yield during both the year 2011-12 and 2012-13.

Economics

Maximum net return of ` 32588/ha along with BCR value of 1.97 was recorded with ammonium sulphate 200 kg/ha followed by control with net return of ` 27586/ha and BCR value of 1.88. Similar results have been reported by Abu-Irmaileh (1981), Westwood and Foy (1999), Mariam and Suwanketnikom (2004).

Manual weeding was found superior with the highest net returns (` 31257/ha) and BCR (1.88) followed by isoproturon 1.0 kg/ha) with net returns (` 29082/ha) and BCR of (1.87). The treatment unweeded control recorded lowest net return (` 26248/ha) and BCR (1.83) followed by Pendimethalin at 1.0 kg/ha with net return of ` 27465/ha and BCR of 1.81. The increase in profit was mainly due to more cured leaf yield of *bidi* tobacco. Similar results were found by Kataria *et al.* (2003), Anonymous (2009-10) and Ramchandra Prasad (2011).

It could be concluded that for securing maximum cured leaf yield of *bidi* tobacco as well as economic returns, ammonium sulphate at 200 kg/ha along with irrigation should be applied. Manual weeding of broomrape was found to be the best practice for weed control.

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Purple nutsedge management by using herbicides alone and in combinations

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ABSTRACT

A field experiment was conducted during summer season of 2015-16 at Junagadh (Gujarat) to evaluate efficacy of a herbicides (halosulfuron-methyl, ethoxysulfuron, glyphosate) and their combinations (glyphosate + halosulfuron, glyphosate + ethoxysulfuron) in managing purple nutsedge (*Cyperus rotundus* L.) under non-crop situation. Maximum purple nutsedge control (92.20%) at 30 days after spraying (DAS) and the lowest regeneration (5.76%) at 60 DAS was recorded with tank-mix glyphosate 1230 g/ha + halosulfuron-methyl 33.75 g/ha at 30 days after emergence (DAE), which was at par with halosulfuron-methyl 80 g/ha at 30 DAE (91.50% and 7.76%, respectively) and halosulfuron-methyl 67.5 g/ha at 30 DAE (89.53% 8.48%, respectively). Ethoxysulfuron 15 g/ha at 30 DAE resulted in significantly the lowest nutsedge control (12.84%) at 30 DAS and the highest regeneration (62.22%) at 60 DAS. The herbicides and their mixtures applied for control of nutsedge during summer season have non-significant effect on plant height and dry matter/plant of succeeding crops, *viz*. groundnut, pearlmillet, cotton and sesame

Purple nutsedge (*Cyperus rotundus* L.) is one of the most troublesome invasive weeds in tropical and subtropical climates and has been described as the world's worst perennial weed. It reproduces predominately by basal bulbs, rhizomes, and tubers, which allow it to flourish under a wide range of growing conditions. Purple nutsedge forms tuber chains where several tubers (2-6 or more) are connected together by means of a slender rhizome-like thread of vascular tissue.

Research studies indicated that post-emergence herbicides, *viz*. glyphosate (Ameena *et al*. 2013), glufosinate-ammonium (Shivashenkaramurthy *et al*. 2008), halosulfuron-methyl (Rathika *et al*. 2013), ethoxysulfuron (Pal *et al*. 2008), trifloxysulfuron-sodium (Gannon *et al*. 2012), imazosulfuron (Riar and Norsworthy 2011), bensulfuron-methyl (Saha 2009), azimsulfuron (Yadav *et al*. 2011), sulfentrazone (Brecke *et al*. 2005), *etc*. have been found very effective for control of purple nutsedge. However, very few among these herbicides are registered for use in India. The sulfonyl urea herbicides, *viz*. halosulfuron-methyl and ethoxysulfuron are registered in the country (Shaik and Subramanyam 2017). Hence considering the problem, an experiment was carried out to test the bioefficacy of halosulfuron-methyl, ethoxysulfuron and glyphosate for managing purple nutsedge.

A field experiment was conducted at College of Agriculture, Junagadh Agricultural University, Junagadh (Gujarat) during summer season of 2015-16 in non-cropped condition. The soil of the experimental plot was clayey in texture and slightly alkaline in reaction as well as low in available nitrogen, available phosphorus and medium in available potash. The experiment, comprising of 10 treatments was laid out in a randomized block design with three replications. The post-emergence spray was done at 30 DAE using knapsack sprayer with flood-jet nozzle. The spray volume of herbicide application was 500 L/ha. The nutsedge control (%) was calculated based on nutsedge count before spray and 30 days after application (DAA).

$$\text{Control (\%)} = 100 - \left(\frac{\text{Nutsedge density 30 DAA}}{\text{Nutsedge density before spray}} \times 100\right)$$

The regeneration (%) was computed on the basis of dead nutsedge count 30 DAA and sprouted nutsedge count at 60 DAA.

$$\text{Regeneration (\%)} = \frac{\text{Sprouted nutsedge density 60 DAA}}{\text{Dead nutsedge density 30 DAA}} \times 100$$

The field bioassay was carried out to ascertain the residual effect of herbicides applied to control nutsedge in summer season on succeeding crops, *viz.* groundnut, pearl millet, cotton and sesame. One row of each crop was grown in each fixed plot during *Kharif* season and plant height and dry matter/plant were recorded at 30 days after sowing of the crops. The data were subjected to statistical analysis by adopting appropriate analysis of variance (Gomez and Gomez 1984). Wherever the F values found significant at 5 per cent level of probability, the critical difference (CD) values were computed for making comparison among the treatment means.

Effect on nutsedge

Nutsedge density was almost similar in all the plots before herbicides spray (at 30 DAE) (**Table 1**). Different treatments have significantly influenced weed density at 30 DAS. Significantly the lowest weed density (2.33/m^2) was observed with application of halosulfuron-methyl 80 g/ha at 30 DAE, which was found statistically comparable to that of tank-mix glyphosate 1230 g/ha + halosulfuron-methyl 33.75 g/ha at 30 DAE and halosulfuron-methyl 67.5 g/ha at 30 DAE. Similarly, different herbicidal treatments did impart their significant influence on nutsedge control. Significantly the highest nutsedge control (92.2%) at 30 DAS was recorded with tank-mix application of glyphosate 1230 g/ha + halosulfuron-methyl 33.75 g/ha at 30 DAE, which remained statistically at par with halosulfuron-methyl 80 g/ha at 30 DAE (91.5%) and halosulfuron-methyl 67.5 g/ha at 30 DAE (89.5%). Among the various herbicidal treatments, ethoxysulfuron 15 g/ha at 30 DAE resulted in significantly the lowest nutsedge control (12.8%) at 30 DAS.

Various treatments have significant influence on dead nutsedge density at 30 DAS and regenerated nutsedge density at 60 DAS (**Table 2**). Post-emergence spray of halosulfuron-methyl 67.5 g/ha at 30 DAE recorded significantly the highest dead nutsedge density (32.67/m^2), which remained statistically at par with tank-mix spray of glyphosate 1230 g/ha + halosulfuron-methyl 33.75 g/ha at 30 DAE. The treatments, *viz.* halosulfuron-methyl 80 g/ha at 30 DAE, ethoxysulfuron 25 g/ha at 30 DAE and glyphosate 1230 g/ha + halosulfuron-methyl 33.75 g/ha at 30 DAE recorded significantly less number of regenerated nutsedge at 60 DAS as compared to the other treatments. The per cent regeneration of nutsedge was significantly influenced by different treatments. Significantly lowest regeneration (5.76%) at 60 DAS was observed under tank-mix spray of glyphosate 1230 g/ha + halosulfuron-methyl 33.75 g/ha at 30 DAE, which remained statistically at par with halosulfuron-methyl 80 g/ha at 30 DAE (7.76%) and halosulfuron-methyl 67.5 g/ha at 30 DAE (8.48%). Among the various herbicidal treatments, ethoxysulfuron 15 g/ha at 30 DAE resulted in significantly lowest nutsedge control (12.84%) at 30 DAS and the highest regeneration (62.22%) at 60 DAS. These results are in conformity with findings of Rathika *et al.* (2013) and Desai *et al.* (2017).

Residual effect on succeeding crops

Herbicides and their mixtures applied for control of nutsedge during summer season have non-significant effect on plant height and dry matter/plant of succeeding crops, *viz.* groundnut, pearlmillet, cotton and sesame.

Table 1. Effect of herbicides on nutsedge control 30 days after spray (DAS)

Treatment	Nutsedge density at 30 DAE (no./m^2)	Nutsedge density at 30 DAS (no./m^2)	Nutsedge control (%)
Halosulfuron 55 g/ha	32.33	8.00	75.25
Halosulfuron 67.5 g/ha	36.33	3.67	89.53
Halosulfuron 80 g/ha	23.33	2.00	91.50
Ethoxysulfuron 15 g/ha	33.67	29.33	12.84
Ethoxysulfuron 20 g/ha	29.67	23.00	22.14
Ethoxysulfuron 25 g/ha	20.67	15.67	24.70
Glyphosate 2460 g/ha	28.33	14.67	47.70
Glyphosate 1230 g/ha + halosulfuron 33.75 g/ha	31.00	2.33	92.20
Glyphosate 1230 g/ha + ethoxysulfuron 10 g/ha	22.33	13.33	39.96
Unweeded check	34.00	43.33	-27.99
LSD (p=0.05)	NS	7.73	5.43

Table 2. Effect of herbicides on nutsedge regeneration 60 days after spray (DAS)

Treatment	Dead nutsedge density at 30 DAS (no./m^2)	Regenerated nutsedge density at 60 DAS (no./m^2)	Regeneration (%)
Halosulfuron 55 g/ha	24.33	3.67	15.19
Halosulfuron 67.5 g/ha	32.67	2.67	8.48
Halosulfuron 80 g/ha	21.33	1.67	7.76
Ethoxysulfuron 15 g/ha	4.33	2.67	62.22
Ethoxysulfuron 20 g/ha	6.67	2.33	35.56
Ethoxysulfuron 25 g/ha	5.00	1.67	33.33
Glyphosate 2460 g/ha	13.67	3.00	22.41
Glyphosate 1230 g/ha + halosulfuron 33.75 g/ha	28.67	1.67	5.76
Glyphosate 1230 g/ha + ethoxysulfuron 10 g/ha	9.00	2.67	28.97
Unweeded check	-9.33	0.00	0.00
LSD (p=0.05)	8.28	1.22	7.31

Table 3. Residual effect of herbicides on *kharif* groundnut, pearlmillet, cotton and sesame at 30 days after sowing

Treatment	Groundnut		Pearlmillet		Cotton		Sesame	
	Plant height (cm)	Dry matter/ plant (g)	Plant height (cm)	Dry matter/ plant (g)	Plant height (cm)	Dry matter/ plant (g)	Plant height (cm)	Dry matter/ plant (g)
Halosulfuron 55 g/ha	7.19	11.31	18.92	8.89	11.49	15.35	14.02	10.48
Halosulfuron 67.5 g/ha	8.08	11.88	19.34	9.44	11.68	15.95	12.80	9.77
Halosulfuron 80 g/ha	7.77	13.07	20.38	8.95	12.13	17.82	13.60	10.55
Ethoxysulfuron 15 g/ha	7.43	11.47	19.65	8.84	11.81	15.30	13.13	11.73
Ethoxysulfuron 20 g/ha	8.16	11.56	20.49	9.38	12.18	16.45	14.13	9.95
Ethoxysulfuron 25 g/ha	8.23	12.20	21.33	10.18	12.54	15.44	13.75	10.63
Glyphosate 2460 g/ha	7.79	13.06	19.83	9.46	11.89	17.81	13.63	11.26
Glyphosate 1230 g/ha + halosulfuron 33.75 g/ha	7.95	11.34	20.55	8.86	12.20	15.10	13.85	10.45
Glyphosate 1230 g/ha + ethoxysulfuron 10 g/ha	8.28	12.02	21.36	9.15	12.55	16.17	14.30	11.34
Unweeded check	7.88	12.37	20.42	9.45	12.15	16.72	14.23	11.27
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Effective control of purple nutsedge under non-cropped condition could be achieved by spraying either tank-mix glyphosate 1230 g/ha + halosulfuron-methyl 33.75 g/ha or halosulfuron-methyl 80 g/ha or halosulfuron-methyl 67.5 g/ha at 30 days after emergence without leaving residual effect on succeeding crops (groundnut, pearlmillet, cotton and sesame) on medium black calcareous clayey soil of South Saurashtra Agro-climatic Zone of Gujarat.

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